TECHNICAL AND ECONOMIC ASSESSMENT OF PRODUCING LIQUID FUELS FROM NATURAL GAS VIA AN ELECTRICITY-BASED ACETYLENE PROCESS
PHASE II

by
Technical Development Department
SNC Inc.

for
CANMET
Energy, Mines and Resources
Canada

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Montreal

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SUMMARY

This cost-shared study has been carried out by the Technical Development Department of SNC Inc. for the Department of Energy, Mines and Resources, CANMET, to investigate the feasibility of liquid fuel (gasoline) production from natural gas via the novel electric-arc acetylene route [DSS Contract No. OSQ84-00209, File No. 14SQ.23440-4-9146].

Commercial manufacture of acetylene must involve rapid heating of the feedstock followed by immediate quenching of the product gas to stabilize the acetylene formed and to minimize the decomposition to carbon and hydrogen.

The advantage of the electric-arc acetylene route is that hydrocarbon feedstock can be heated very rapidly (< 5 ms), therefore the conversion is high compared to other thermal processes namely the Wulff's regenerative or the partial oxidation route (Tedeschi 1982). The disadvantage being that energy requirement is high, consequently the proposed method is feasible where electricity is cheap and available.

Experimental Results

As a part of the study, an experimental program was carried out under a subcontract to AVCO Research Laboratory Inc. using their existing 100-kW bench-scale arc-reactor facility at Everett, Massachussetts. The main objective was to optimize the operating conditions by maximizing the acetylene product with minimum carbon formation and low specific energy requirement (SER* = kWh/ kg of product).

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* SER_1 = kWh/kg of acetylene
* SER_2 = kWh/kg of acetylene and ethylene

Thirty-three exploratory runs were made with two types of feed gas (methane and methane/hydrogen mixture) and three types of quenches (hydrogen, methane and ethane) under selected range of operating conditions as shown in Table 2-1 (Chapter 2).

Description of the electric-arc reactor unit, experimental procedure and the results obtained are presented in the AVCO report attached in Appendix B. A summary of the results and conclusions are given below:

- Runs made with methane (CH_4) as a feedstock gave higher acetylene yields and lower specific energy requirement compared to CH_4/H_2 feed mixture. Addition of hydrogen to the CH_4 feed also resulted in the dilution of the product gas stream. Hence, CH_4/H_2 feed mixture was eliminated from further consideration.

- For the conditions investigated, the optimum methane feedrate was found to be 8.3 l/s (18.7 scfm).

- The suitable quench mediums are hydrogen or ethane. The role of hydrogen during quenching is mainly physical in nature, whereas ethane also reacts to form ethylene. The use of CH_4 as a quench gave poorer results compared to hydrogen or ethane quench runs, since the temperature in the quench zone is low (> 1200°C) for significant conversion of CH_4 to the desired products.

- At an optimum methane feedrate of 8.3 l/s (18.7 scfm), the optimum hydrogen quench rate is 6.7 l/s (15 scfm). Similarly, the optimum ethane quench rate is 2.2 l/s (5 scfm).

SUMMARY (Cont'd)

- For ethane quench case, the location of the quench ports was found to be an important parameter. Therefore, the primary quench distance of 15 cm was reduced to 7.5 cm, thereby allowing ethane to be introduced closer to the arc zone.

- Subsequent runs made with CH_4 feed and ethane quench using the short anode (i.e., at reduced primary quench distance of 7.5 cm) gave higher overall product yields (Y_2) and lower SER_2 values as shown below. Comparative results with hydrogen quench are also presented.

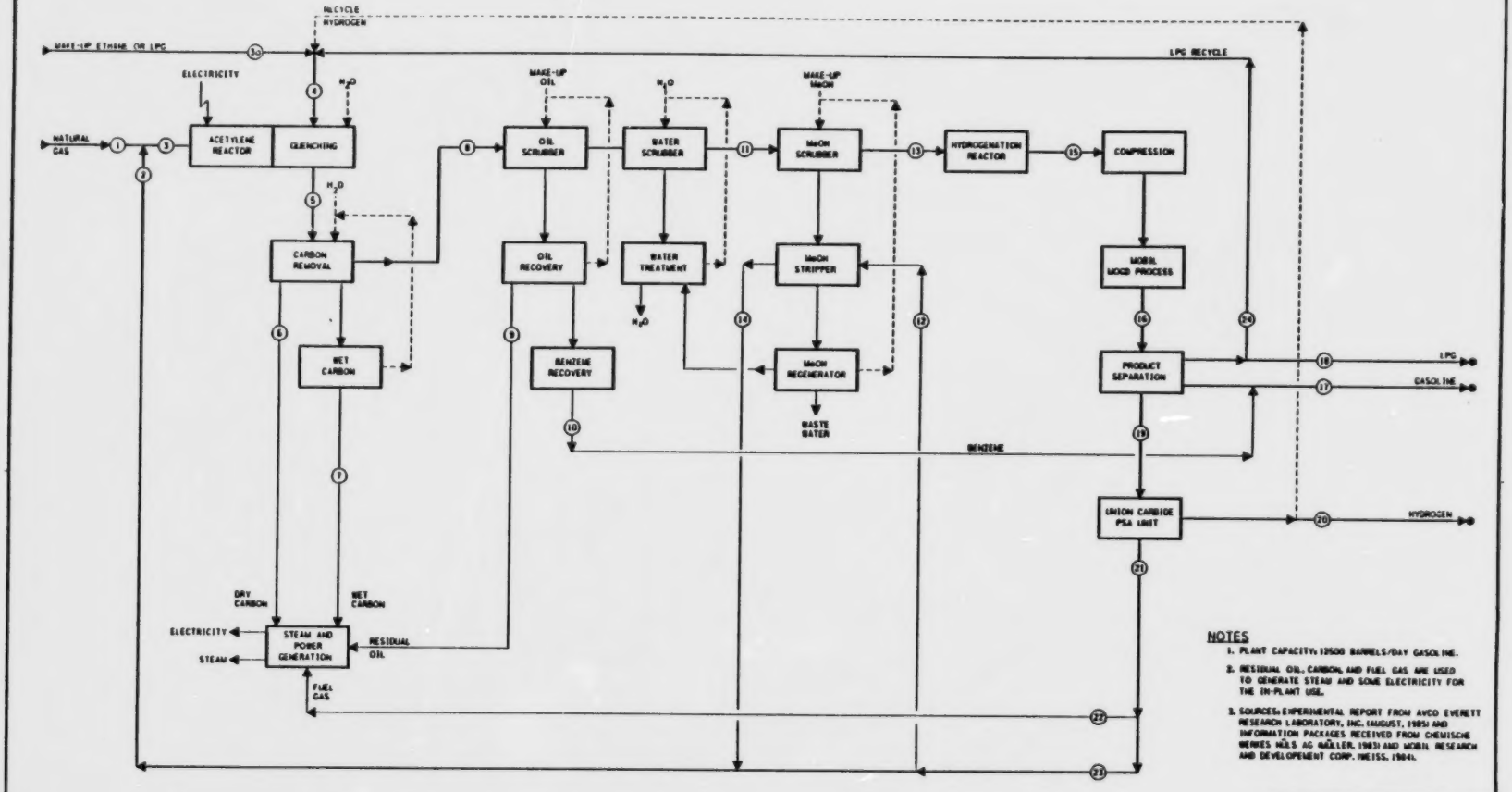
	Hydrogen Quench	Ethane Quench	
		Normal Anode	Short Anode
Concentration of C_2H_2, vol%	8.2-13.1	13.7-15.8	13.3-15.6
Yields*, wt%			
Y_1	51-83	56-76	57-75
Y_2	54-85	33-61	36-65
Specific Energy Requirement**			
SER_1	7.8-8.9	8.0-8.8	7.9-8.7
SER_2	7.6-8.5	6.8-8.1	5.8-7.3

- In general, the SER changes marginally with pressure, however, the yield and concentration increases initially with increase in pressure but tend to level off or decrease at higher pressures. For all cases, the optimum pressure is in the range of 25-35 kPa (190-260 mm Hg).

---

* Y_1 = (C in C_2H_2) / (C in feed)
Y_2 = (C in C_2H_2 + C_2H_4) / (C in feed + quench)

** SER_1 = kWh/kg of C_2H_2
SER_2 = kWh/kg of C_2H_2 + C_2H_4



NOTES

1. PLANT CAPACITY: 12500 BARRELS/DAY GASOLINE.
2. RESIDUAL OIL, CARBON, AND FUEL GAS ARE USED TO GENERATE STEAM AND SOME ELECTRICITY FOR THE IN-PLANT USE.
3. SOURCES: EXPERIMENTAL REPORT FROM AVCO EVERETT RESEARCH LABORATORY, INC. (AUGUST, 1985) AND INFORMATION PACKAGES RECEIVED FROM CHEMISCHE WERKES HÜLS AG (MÜLLER, 1983) AND MOBIL RESEARCH AND DEVELOPMENT CORP. (WEISS, 1984).

STREAM NO	1	2	3	3a	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
STREAM DESCRIPTION FLOWRATE kg/h	NATURAL GAS	RECYCLE GAS	TOTAL FEED	MAKE-UP ETHANE OR LPG	QUENCH	REACTOR EFFLUENT	DRY CARBON	WET CARBON	GAS TO PRODUCT RECOVERY	RESIDUAL OIL	BENZENE	GAS TO MeOH SCRUBBER	STRIPPING GAS	GAS TO HYDROGEN-ATION UNIT	RECYCLE GAS TO REACTOR	OLEFIN RICH FEED	MOBIL REACTOR OUTLET	GASOLINE PRODUCT	LPG BY-PRODUCT	OFF GAS	HYDROGEN BY-PRODUCT	RECYCLE GAS	FUEL GAS	RECYCLE GAS TO REACTOR	LPG RECYCLE
ETHANE QUENCH	56439	18132	74571	35920	35920	110491	2308	1153	107699	509	258	108061	9733	99208	18132	99208	99208	60768	12918	25780	9500	16280	6547	9733	0
HYDROGEN QUENCH	95291	21704	116995	0	15252	132247	2976	1487	128646	615	310	129833	13673	120784	21704	120784	120784	60699	14664	45731	11782	18777	5104	13673	0
LPG QUENCH	73605	22639	96224	12129	30706	126950	2924	1462	125411	2848	639	121333	12209	110335	22639	110335	110335	60977	0	51420	9268	22152	9943	12209	10577

SNC Inc.

CLIENT: CANMET ENERGY MINES & RESOURCES, CANADA

PROJECT: GASOLINE PRODUCTION FROM NATURAL GAS VIA ELECTRIC ARC REACTOR

TITLE: OVERALL BLOCK FLOW DIAGRAM OF A CONCEPTUAL COMMERCIAL PLANT (12500 bbl/d GASOLINE PRODUCT)

CONTRACT: 7,3,6,6 | CODE ID/ DESIGN | SERIE | REV

Conceptual Plant Design

For techno-economic evaluation, conceptual designs with overall material, energy and utility balances were prepared for a commercial plant producing 12 500 bbl/d of liquid fuel (gasoline) product. The following process options were selected:

- natural gas feed with hydrogen quench
- natural gas feed with ethane quench
- natural gas feed with LPG (mixed propane/butane) quench

Experimental Runs No. 8 and 30 were taken as a basis for the hydrogen and ethane quench cases, respectively. For a large scale reactor, predictions for product yields, conversion and SERs were made by AVCO based on an arc-acetylene reactor model developed earlier for coal [AVCO 1981] which was modified for natural gas feed.

Although no experimental tests were made with LPG quench, this case was added to allow comparison. Run No. 9 (with no quench) was used to estimate the arc-reactor product yield. Conversion of LPG to the desired product during quenching was estimated based on commercial operation data supplied by Chemische Werke Hüls, Germany [Müller 1983].

Figure 1 is a block flow diagram showing the interrelationship between the various procesing areas for an integrated liquid fuel plant. The overall plant consists of an acetylene reactor system, acetylene hydrogenation, olefin oligomerization (Mobil Olefin to Gasoline and Distillate Process) and hydrogen recovery (Union Carbide's Pressure Swing Adsorption) units along with the required support, utility and offsite facilities to comprise an integrated self-sufficient operation.

Table 1 Technical Comparison of the Electric-Arc Acetylene Process to Produce Liquid Fuel Using Different Quench Mediums

Plant Capacity: 12 500 bbl/d gasoline product

	Ethane Quench	Hydrogen Quench	LPG Quench
Natural Gas Conversion, wt%	91	91	91
CH_4 Conversion[1], Prequench, wt%	95	95	95
After quench*, wt%	92	95	84
Reactor Product Yield, wt%			
. Acetylene Yield[1]	79.3	74.1	78.3
. Acetylene + Ethylene Yield[1]	93.2	82.6	88.0
Reactor SER (Pre-Quench)			
. kWh/kg of acetylene	10.4	8.5	8.5
. kWh/kg of acetylene + ethylene	8.9	7.6	7.6
Reactor SER (After Quench)**			
. kWh/kg of acetylene	10.7	8.5	8.5
. kWh/kg of acetylene + ethylene	5.8	7.6	6.4
Process Input, kg/kg of gasoline			
. Natural Gas	0.93	1.57	1.21
. Quench (Net)	0.59	-	0.20
Overall Process SER, kWh/kg of gasoline	7.5	9.9	7.0
Byproduct Output, kg/kg of gasoline			
. Hydrogen	0.16	0.19	0.15
. LPG	0.21	0.24	-
Total Energy Input, GJ/h	6 427	7 222	6 060
Total Energy Output, GJ/h	4 604	4 952	3 922
Thermal Efficiency, %			
. Overall Product	71.6	68.6	64.7
. Liquid Product	43.8	38.9	46.6

1. based on total CH_4 feed to the reactor (including CH_4 in the recycle stream)

* Lower overall CH_4 conversion (after quench) is due to some methane formation during LPG quenching.

** Reactor SER_1 (after quench) based on acetylene yield is the same as SER_1 (pre quench) since negligible acetylene is formed during quenching.

Natural gas, electricity, ethane or LPG as quench, and make-up water are the major process inputs. Gasoline is the main product. LPG (mixed propane/butane) and hydrogen are recovered as byproducts. In the LPG case, all the LPG is recycled as quench. In all cases, unreacted methane is recovered and recycled to the arc-reactor.

A technical evaluation of the three designated plant operating configurations is summarized in Table 1. Overall conversion of natural gas is about 90 wt% and acetylene yield is in the range of 74-79 wt%, the highest being in the case of ethane quench.

Although the reactor specific energy requirement for ethane quench (SER_1 = 10.7 kWh/kg of acetylene) is high, the SER_2 value is low (5.8 kWh/kg of acetylene + ethylene). Similarly, the thermal efficiency of the process is 72% for ethane quench compared to 69% for hydrogen quench and 65% in the case of LPG quench.

Capital, Operating and Production Cost Estimates

Capital cost estimates for the plant battery limits were developed on the basis of equipment cost and data received from various process developers and licensors from Germany, USA and Canada. These data were updated to January 1986 and also adjusted to reflect conditons prevailing in Québec (Canada). The offsite facilities were estimated by SNC based on in-house data. Where information was not available, factored-cost estimation procedure was used. Details are given in Chapter 4, some of the assumptions and basic criteria are summarized in Table 2.

Table 2 Basic Financial Assumptions and Economic Criteria

Plant Capacity	:	12 500 bbl/d gasoline
Plant Location	:	Québec
Base Year of Estimate	:	January 1986
Plant Start-up Date	:	1991
Construction Period	:	3 years (1988-1990)
Plant Construction Schedule	:	
Year		%
1		22
2		48
3		30
Project and Estimating Contingency		10%
Tax Rate	:	37%
Plant Operation		
1991	:	7200 hours/year
1992-2010	:	8000 hours/year
Depreciation Method		Straight line
Plant	:	20 years
All Other Items	:	5 years
Land	:	Non depreciable
Working Capital	:	Non depreciable
Raw Material & Cost		
Natural Gas	:	\$3.03/GJ (\$3.20/10^6 Btu)
Electricity	:	2¢/kWh
LPG Quench	:	18.3¢/l (\$183/m^3 or 34.2¢/kg)
Ethane Quench	:	11.1¢/l (\$110/m^3 or 29.7¢/kg)
Chemicals/Solvents/Water Cost		
Scrubbing Oil	:	18.9¢/kg (\$30/bbl)
Methanol	:	\$235/t (70.5¢/US gal)
Make-up Water	:	5.3¢/m^3 (20¢/US gal)
Products/By-products Price		
Gasoline	:	35¢/l
Hydrogen	:	\$7.58 GJ (\$8/10^6 Btu)
LPG	:	18.3¢/l (\$183/m^3 or 34.2¢/kg)
Financial Analysis		
Constant Dollars	:	assuming 100% equity with no escalation
Current Dollars	:	40% financing at 12% interest rate and escalation at 5% per annum.

Table 3 provides a breakdown of capital cost estimates by process areas, expressed in "constant" January 1986 dollars*. The total installed plant cost (TIPC) includes all the equipment for onsite and offsite facilites, bulk materials, labour, engineering and project management, and other indirect construction costs. A contingency of 10% has been added.

Based on discussions with Federal and Provincial agencies, it was assumed that a project of this nature would attract a 15% grant towards the capital cost of the plant. Also, subsidies currently available from Hydro-Québec under "Le programme d'aide à l'implantation des électro-technologies" was considered.

Annual operating, maintenance and production costs expressed in "constant" January 1986 dollars are presented in Table 4 for 8000 hours of operation/year. Raw material, utilities, catalysts and chemical costs have been calculated using the unit cost data given in Table 2. The total annual production cost, excluding depreciation, may be summarized as follows:

	Ethane Quench	Hydrogen Quench	LPG Quench
Total Production Cost, $ million	279.96	276.49	248.48
Byproduct Credits, $ million			
Hydrogen	(68.41)	(84.27)	(66.75)
LPG	(35.34)	(40.12)	-
Net Production Cost, $ million	176.21	152.10	181.73
Gasoline Production Cost, ¢/l (excl. depreciation)	26.5	22.9	27.4

* For "current" dollar analysis, capital and operating costs are presented in Appendix E.

Table 3 Capital Cost Estimates and Total Plant Investment, in millions of Canadian Dollars (January 1986)

Plant Capacity: 12 500 bbl/d gasoline product

	Ethane Quench	Hydrogen Quench	LPG Quench
Acetylene Production, Carbon Black Recovery and Higher Acetylene Separation	169.64	192.80	186.50
Acetylene Hydrogenation Unit	29.64	34.00	31.93
Mobil MOGD Process	70.54	76.26	74.60
PSA Unit for H_2 Recovery	24.93	51.73	24.50
Total Onsite Cost	294.75	354.79	317.53
Steam Generation	4.06	4.68	3.70
Incineration	1.95	1.87	2.03
Water Treatment	1.07	1.20	1.0
Electrical Equipment	80.33	97.34	83.80
Steam Cooling and Process H_2O	17.63	19.62	17.53
Refrigeration	8.33	9.43	7.74
Site Preparation, Bldgs, etc.	23.42	23.42	23.42
Sewer, Fire Protection, Fence & Flare	5.0	5.0	5.0
Air Supply	1.74	1.74	1.74
Product Shipping and Storage	11.00	11.86	10.81
Inter Connecting Pipe Racks	6.36	7.34	6.53
Total Plant Cost	455.64	538.29	480.83
Contingency	45.56	53.81	48.07
Total Installed Plant Cost (TIPC)	501.20	592.10	528.90
Subsidies/Grants			
Capital Cost Grant	(75.18)	(88.81)	(79.33)
Hydro-Québec Grant	(39.16)	(37.44)	(40.38)
Total Plant Cost, Net of Grants	386.86	465.85	409.19
Indirect Capital Investment			
License and Prepaid Royalties	1.79	1.79	1.79
Initial Catalyst and Chemicals	1.40	2.26	1.74
Start-up and Other Costs	15.04	17.76	15.87
Working Capital*	15.04	17.76	15.87
Land*	1.20	1.20	1.20
Total Capital Investment	421.33	506.62	445.66

* non-depreciable items

Table 4 Annual Operating, Maintenance and Production Cost, in millions of Canadian Dollars (January 1986)

Plant Capacity: 12 500 bbl/d gasoline product
Plant Operation: 8 000 hours/year

	Ethane Quench	Hydrogen Quench*	LPG Quench
Natural Gas	71.84	121.30	93.70
Electricity	72.48	96.00	68.00
Quench (Ethane)	85.35	-	-
(LPG)	-	-	33.18
Catalyst and Chemicals**	16.16	18.46	17.22
Make-up Water	0.38	0.46	0.35
Royalties (10 years)	2.40	3.89	3.15
Labour, Supervision and Operating Supplies	2.61	2.61	2.61
Maintenance (incl. labour)	15.04	17.76	15.87
Property Taxes and Insurance	7.52	8.88	7.93
Overhead and Administration	6.18	7.13	6.47
Total Production Cost (excl. depreciation)	279.96	276.49	248.48

* hydrogen generated in the plant is recycled to the arc reactors as quench.

** for proprietory reasons, MOGD royalties are included by the process developer in the annual cost of catalyst consumed.

If byproduct credits are taken, the unit production cost of gasoline (excl. depreciation) is about 23¢/l when hydrogen is used as a quench and 27.4 ¢/l for the LPG quench case.

Financial Analysis

To account for depreciation, capital recovery cost and taxes over the life of the project, financial analysis were carried out for each of the three cases under two scenarios:

- in constant dollars assuming 100% equity financing with no escalation

- in current dollars assuming 40% debt financing with escalation at 5% per annum. Interest rate on debt is taken as 12% per annum.

The life of the project is considered to be 23 years; 3 years of construction and 20 years of operation. At the end of the project, the cost of land and working capital are fully recovered. For other capital cost components, a zero salvage value is assumed.

Capital cost allowance (depreciation) is calculated on a straight line basis according to the schedule specified in Table 2. Operating losses, if any, are carried forward for up to 5 years to calculate taxable income. Federal and Provincial income taxes are estimated as 37% of taxable income.

For current dollar analysis, 40% of the capital cost of the plant (TIPC) is assumed to be financed by long term debt. Interests are capitalized during the first three years (construction period) as per the plant construction schedule and the loan is

repaid in ten equal annual instalments starting from the first year of production. The loan bears an interest of 12% per annum.

An inflation factor of 5% per annum over the life of the project is assumed. While this value is not to be interpreted as a forecast, it creates a scenario which corresponds to the current conditions and allows comparison of internal rates of return with alternate earning opportunities.

For each case, complete Profit and Loss as well as Source and Application of Funds Statements are provided in Appendix E. The key results are summarized in Table 5.

The financial analysis in constant dollars* with 100% equity financing for the liquid fuel plant indicates that an internal rate of return on equity (ROE) ranges from 8.3-12.6% before taxes in "real" terms and 6.1-9.0% after taxes. For a project of this nature, this may be considered as an acceptable rate of return based on gasoline transfer price of 35¢/l at the plant gate.

In the current dollar analysis with 40% financing, the ROE ranges from 14.1-20.2% before taxes and 10.9-15.5% after taxes, being highest for the hydrogen quench case. The payback period is 5.5 years. Debt coverage ratio is greater than 1.5, considered as a typical minimum by the lending institutions.

Sensitivity Analyses

For each of the three designated cases, sensitivity analyses were also made to determine the impact of variations in the key cost variables on the project feasibility. A complete set is

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* in constant dollar analysis, return on equity is expressed in "real" terms, i.e., current rates minus inflation.

attached in Appendix F. Figure 2 shows a typical sensitivity curve for the selected hydrogen case. The dotted curve represents extrapolation beyond the specified ranges.

In general, the project is most sensitive to revenues, particularly the gasoline price, moderately sensitive to the plant cost and less sensitive to the cost of raw materials.

Figure 2 can be used for single as well as multivariable study. For example, a 10% increase in the transfer price of gasoline (i.e., to 38.5¢/l) would increase the ROE from 20.2% to 25.7% before taxes. Similarly, a 10% increase in the total plant cost reduces the ROE to 17.5%. A combination of these two events, would yield 23% before taxes.

For the selected hydrogen case, two additional sensitivity analyses were made to evaluate the impact of inflation rate and debt/equity ratio on the project. Prices of energy related items such as gasoline, hydrogen, LPG, ethane, natural gas and electricity were escalated at the rate of 3% per annum while for all other operating cost components, an inflation factor of 5% was assumed. The return on equity dropped to a marginal value of 13.5% before taxes. It should be noted, however, that the 2% differential in the escalation rate is unlikely to be sustained on a long-term basis (i.e., 20 years life of the project).

With higher debt/equity ratio, i.e., 60% financing, the ROE increased marginally to 21.6% before taxes and 16.8% after taxes. The average debt coverage ratio is 1.4.

Table 5 Financial Analysis Results

	Ethane Quench	Hydrogen Quench	LPG Quench
Constant Dollar Analysis *			
ROE (before taxes),%	10.2	12.6	8.3
(after taxes), %	7.4	9.0	6.1
Payback Period, years			
(before taxes), %	7.7	6.5	9.0
(after taxes),%	10.0	8.6	11.3
Current Dollar Analysis			
ROE (before taxes),%	16.7	20.2	14.1
(after taxes),%	12.9	15.5	10.9
Payback Period, years			
(before taxes)	7.2	5.5	9.1
(after taxes)	9.6	7.4	11.0
Average Return on Sales, %	7.0	10.3	6.5
Average Return on Fixed Assets, %	10.5	13.7	8.7
Debt Coverage Ratio			
Minimum	1.5	1.7	1.4
Year	1992	1992	1992
Maximum	1.8	2.1	1.6
Year	2000	2000	2000

* in constant dollar analysis, return on equity is expressed in real terms, i.e., current rate minus inflation.

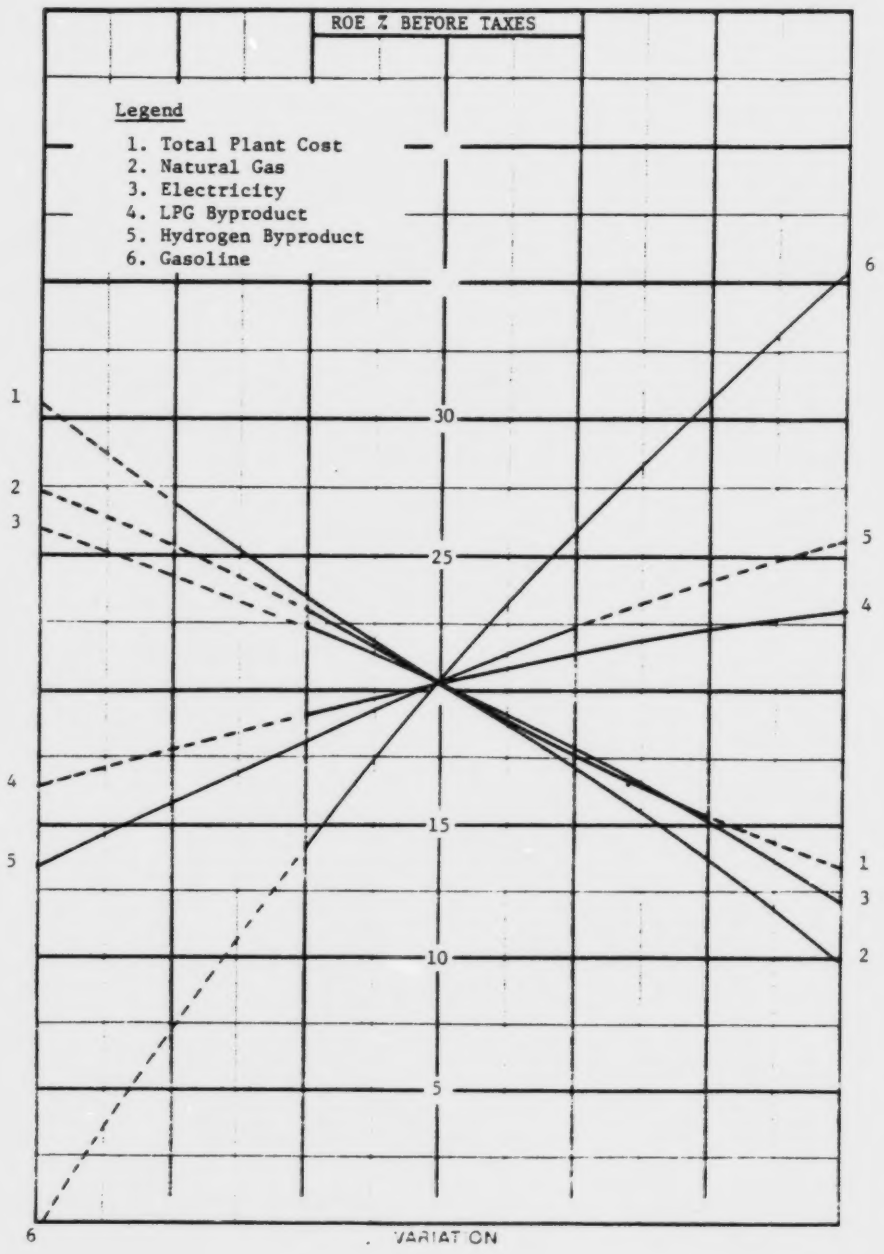

Figure 2-1 Sensitivity Analysis for the Hydrogen Quench Case (in Current Dollars assuming 40% Debt Financing)

The foregoing analysis indicates that production of liquid fuel from natural gas via the novel acetylene route is feasible and should be pursued further. The proposed route is also less capital intensive. The capital investment of $40 000/daily barrel of gasoline product is 30% lower than other synfuel technologies, such as Mobil MTG and Fischer-Tropsch processes [Oil and Gas Journal (1985), Mikhlin et al (1985)].

The electric-arc process configuration with hydrogen quench is the most attractive route for the production of gasoline from natural gas. All technologies considered in the conceptual plant design are commercially available except for the hydrogen quench system and the Mobil MOGD process.

In this study, the electric-arc reactor with hydrogen quench was demonstrated on a process development unit. The scale-up of the electric-arc reactor with hydrogen quench is not considered to be critical, since similar reactor configurations with LPG quench have been in commercial operation at Chemische Werke Hüls, in Germany for over 40 years. The MOGD process has been demonstrated on a pilot scale by Mobil Oil Corporation. In this case as well, a similar Mobil MTG process with identical catalyst and reactor configuration but operating under different conditions has been commercialized now in New Zealand.

In conclusion, the novel scheme for liquid fuel production via acetylene offers an attractive synfuel alternative, particularly for locations, where cheap electricity and natural gas are available. The proposed route would also yield other spinoff benefits such as acetylene-based chemical industries, since cheap acetylene may be recovered to produce other desired hydrocarbon products.

1.0 INTRODUCTION

1.0 INTRODUCTION

This study has been carried out by the Technical Development Department of SNC Inc. as a cost-shared contract for CANMET, Department of Energy, Mines and Resources (DSS Contract No. OSQ84-00209, File No. 14SQ.23440-4-9146).

1.1 OBJECTIVES

The main objectives and scope of the study are:

- to investigate the feasibility of liquid fuel (gasoline) production from natural gas via the acetylene route using the electric-arc process.

- to carry out an experimental program under subcontract to AVCO Everett Laboratory Inc. using a 100-kW arc-acetylene process development unit (PDU). Specific objectives included:

  - modification of the existing PDU from coal feed to natural gas (methane) feed

  - to test two types of feed (methane and methane/hydrogen mixture) and three types of quench (hydrogen, methane and ethane) under selected range of operating conditions

  - to determine optimum set of reactor operating conditions by maximizing the conversion and desired product (acetylene and ethylene) yields* and by minimizing the specific energy requirement** (SER) and undesirable carbon formation

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* Y_1 = (C in C_2H_2) / (C in feed)
Y_2 = (C in C_2H_2 + C_2H_4) / (C in feed + quench)

** SER_1 = kWh/kg of C_2H_2
SER_2 = kWh/kg of C_2H_2 + C_2H_4

1.1 **OBJECTIVES** (Cont'd)

- to predict the conversion, product yields and SERs for a large-scale reactor based on pilot plant studies (1 MW reactor) made earlier by AVCO for coal.

- to develop a conceptual plant design of a liquid fuel plant producing 12 500 bbl/d (about 2 million l/d) of gasoline product. The electric-arc reactor process with three quench options was selected:

  - natural gas feed with ethane quench
  - natural gas feed with hydrogen quench
  - natural gas feed with LPG (propane/butane) quench

- to estimate capital, operating, maintenance and product costs for gasoline production from natural gas via the acetylene route

- to provide financial analyses in both "constant" and "current" dollars

- to make sensitivity analyses by varying the key cost components and to determine the impact on the overall feasibility of the project

- to carry out a techno-economic assessment and evaluation of the designated process options.

1.2 BACKGROUND

Canada has surplus natural gas and in some provinces such as Québec, abundant as well as cheap electricity is also available. Estimate of the established reserves of marketable natural gas from all non-frontier areas is about 76 EJ or 72 trillion cubic feet [Edge 1981]. In addition, substantial gas reserves are known to exist in the frontier as well as the offshore areas near Sable Island.

In general, various energy options have been considered and one of the strategies has been to conserve energy and encourage utilization of natural gas for oil. The proposed route involves the use of electricity-based methods for conversion of natural gas to liquid fuels and/or hydrocarbon products via acetylene. This route has two main advantages:

- combined use of both surplus natural gas and cheap electricity to produce valuable end-products

- decrease Canada's dependence on imported oil, particularly for Eastern Canada, by shifting to utilization of huge shut-in gas reserves available in the country.

The concept of converting natural gas or any hydrocarbon feedstock to intermediate acetylene using the electricity-based methods is not new. In fact, the development of a commercial process for the manufacture of acetylene from hydrocarbons began as early as 1920 when Badische Aniline und Soda-Fabrik (BASF) initiated a research program, based on Berthelot's laboratory investigation on conversion of low-molecular weight aliphatic hydrocarbons to acetylene by means of thermal cracking [Miller 1966].

1.2 BACKGROUND (Cont'd)

Development of the electric-arc process by BASF led to the first commercial operation at Chemische Werke Hüls (Germany) in 1939. In the USA, commercial manufacture by Monsanto Chemicals in 1940 at Texas City produced about 50 000 t/yr of acetylene. In the following years, rapid expansion occurred and several acetylene-based chemical plants were built worldwide until about mid-1960's when acetylene was gradually displaced by cheaper petroleum-derived ethylene as a feedstock for petrochemicals production.

E.I. Dupont de Nemours and Company operated a modified "rotating" electric-arc process [Doukas 1963, Cichelli 1963] at Montagne, Michigan, to produce about 20 000 t/yr of acetylene from natural gas for chloroprene/neoprene rubber manufacturing plant. The Dupont facility was closed down in 1973 due to poor economics and operating problems. The worldwide annual capacity of acetylene estimated at 1 110 000 t/yr in 1965 fell to 800 000 t/yr in 1976 and to only 300 000 t/yr in 1983 [Miller 1966, Tedeschi 1982].

The oil crisis in the 1970's, however, resulted in renewed interest in the electric-arc/plasma technology. New and flexible electric-arc/plasma reactor systems were developed by Westinghouse, AVCO, Plasma Energy Corporation, SKF, Aerospatiale and others for various applications such as iron making, ferro-alloys, chip melting, chemical processing, etc. A review is presented elsewhere [Mikhlin et al, SNC 1985]. In hydrocarbon processing, efforts were mainly directed towards the use of available feedstocks such as natural gas, heavy oil, wood and coal.

1.2 BACKGROUND (Cont'd)

In 1971, the Office of Coal Research (now US Department of Energy) awarded a contract to AVCO, Massachusetts to develop an electric-arc process for conversion of coal to acetylene [Gannon and Krukonis 1971]. Initial tests were made in a 100-kW process development unit and later in a 1-MW pilot plant reactor. Westinghouse [Fey and Reed 1980] investigated the conversion of methane to acetylene using self-stabilizing arc reactors ranging in power from 1-3 MW.

In Federal Republic of Germany, similar work was carried out by Chemische Werke Hüls [Müller and Peuckert 1983] and Bergbau-Forschung GmbH [Beirs et al 1985]. Hüls developed the arc-coal acetylene process in a 80-kW reactor and later tested on a 0.5-MW pilot scale.

In Canada, a contract research to convert coke to acetylene in a hydrogen plasma under reduced pressure was sponsored by CANMET at Université de Sherbrooke. Other researchers directed their efforts on production of synthesis gas from coal, wood, or peat. Techno-economic evaluation by Noranda [Gauvin and Duncan 1982] to make methanol from peat and by PAPRICAN [Simonsen 1985] for fuel gas from wood using electric-arc/plasma methods show that the proposed routes are not economical.

In general, a common principle characterizes all hydrocarbon-based acetylene processes. Typically, hydrocarbon feedstock is subjected to an intense energy source whereby it is heated to between 1200° and 1800°C in a very short time (5-20 ms). At 1200°C or higher temperatures, acetylene has lower free energy (i.e., more stable) than any other hydrocarbons, therefore it is the predominant specie formed. But even at these temperatures,

acetylene is less stable than its elements (carbon and hydrogen). Therefore, the cracked gas containing acetylene, hydrogen and other elements must be rapidly cooled (< 10 ms) to 500°C or lower to stabilize the acetylene formed and prevent it from decomposing to carbon and hydrogen.

The methods do, however, differ in the way necessary energy for the reaction is supplied to the feedstock. In the electric-arc process, heat is directly transferred by means of high temperature electric arc. In the hydrogen plasma acetylene process, hydrogen is fed into the arc zone and heated to a plasma state. The exiting stream of hot hydrogen plasma is then used to provide heat to the incoming feedstock. In the conventional process, namely the Wulff process, heat is supplied by a regenerative furnace. Other processes such as the one-stage and two-stage partial oxidation processes (BASF, Sachsse, Union Carbide, Montecatini) involve partial combustion of the feedstock to provide the heat and attain the required reaction temperature (> 1200°C).

The advantage of the electric-arc method over conventional processes is that energy is applied very rapidly to the feedstock, therefore, the conversion and product yields are significantly higher. The residence time is relatively short, in the order of milliseconds. Thermodynamic and kinetic considerations favouring the use of electricity-based methods are given in Appendix A. The disadvantage is that energy consumption is high, consequently, the method could be feasible for locations where electricity is cheap and available.

In Phase I of the study, three types of reactor configurations were evaluated [Cooke and Ashraf 1985] namely the electric-arc, hydrogen plasma and concentric-tube resistance heater.

1.2 BACKGROUND (Cont'd)

Preliminary techno-economic evaluation carried out for Québec location indicated that the electric-arc method is promising for liquid fuel production from natural gas. Also, higher conversion and improved product yields could be attained by judicious choice of operating conditions and by rapid quenching with a suitable medium.

The present Phase II of the study was, therefore, aimed at identifying the optimum operating conditions and suitable quench mediums so as to determine if an economic advantage exists for a particular quench system over another. Specific objectives were highlighted earlier.

1.3 TECHNO-ECONOMIC CRITERIA

Basic criteria used in the study for the conceptual plant design and techno-economic assessment are summarized below:

1.3.1 Feedstock

Typical composition of the natural gas from local gas distributors [Levesque 1982, Noël 1985] is as follows:

	vol %
Nitrogen	1.880
Carbon Dioxide	0.334
Methane	95.405
Ethane	2.217
Propane	0.151
i - Butane	0.007
n - Butane	0.006
	100.00

Higher Heating Value	
at 101.325 kPa, 15°C, dry	37.65 MJ/m^3
at 30 inches of Hg, 60°F, sat	994.0 Btu/scf

1.3 TECHNO-ECONOMIC CRITERIA (Cont'd)

1.3.2 Product Criteria

Gasoline was designated as the main liquid fuel product.

LPG and hydrogen are recovered as byproducts. In the LPG quench case, all the LPG is recycled. In all the three cases, unreacted methane is recovered and recycled to the arc reactors.

1.3.3 Plant Capacity and Location

The capacity of the liquid fuel plant considered for each of the three process options is 12 500 bbl/d (1 987 350 litre/d) gasoline product. The onstream factor is assumed to be 7 200 hours in the first year of production and 8 000 hours in the subsequent years.

The study is not site specific, however, to establish the bases for cost estimates and financial analysis the plant is assumed to be located in the Province of Québec, Canada.

The conceptual design is developed for a greenfield site with self-sufficient, integrated operation. Natural gas, electricity, LPG or ethane as quench are major raw materials and process inputs.

Make-up water is assumed to be available at the site. Steam required for the process is generated onsite by recovering process heat and burning waste carbon, residual oil and fuel gas. Electricity may also be generated onsite with excess fuel gas. The balance of the electricity required is purchased from Hydro-Québec.

1.3 TECHNO-ECONOMIC CRITERIA (Cont'd)

1.3.4 Overall and Liquid Product Efficiency

As one of the criteria for technology evaluation, overall and liquid product efficiencies are defined. The "overall" product efficiency is the total higher-heating-value (HHV) of all the products divided by the total input energy of natural gas, LPG or ethane, and electricity. For the total electricity consumed (including losses), a thermal equivalent factor of 3 600 kJ/kWh has been applied.

The "liquid" efficiency is based on gasoline product.

1.3.5 Environmental Aspects

The conceptual plant design will meet the existing local, provincial and federal environmental regulations on particulates, liquid and gaseous effluents.

1.3.6 Cost Estimates

Capital, operating, maintenance and product cost estimates are developed in January 1986 dollars. The accuracy of the estimates is considered to be ±20%.

Equipment cost and investment data received from the manufacturers, process developers, and licensors are taken as a basis for estimating the capital cost of the conceptual commercial plants. Where information was not available, factored-cost estimation procedure or SNC inhouse data for a similar unit was used. In all cases, the data were adjusted to reflect conditions in Québec. Where necessary, the estimates were updated to January 1986 using standard cost indexes.

1.3 TECHNO-ECONOMIC CRITERIA (Cont'd)

1.3.6 Cost Estimate (Cont'd)

For the designated conceptual plants, a 3-year construction period (1988-1990) and a 20-year operating life (1991-2010) was assumed. A straight-line depreciation method was applied. At the end of the project, the plant is assumed to have zero salvage value. Land and working capital are non-depreciable.

Details of the methodology and cost-estimating procedure are given in Chapter 4. Other financial assumptions and economic criteria are also presented.

2.0 EXPERIMENTAL TEST PROGRAM

2.0 EXPERIMENTAL TEST PROGRAM

One of the main objectives of this study was to determine an optimum set of operating conditions for each of the three designated configurations for producing acetylene in an electric-arc reactor process.

An experimental program was carried out under a subcontract to AVCO Research Laboratories using their existing 100-kW PDU scale arc-reactor facility at Wilmington, Massachusetts. The PDU built earlier for coal feed was modified for natural gas feed and to test various quench options so as to maximize the desired product yields and minimize the energy requirement.

A report on the experimental program prepared by AVCO is attached in Appendix B. This section summarizes the scope of the test program and the results obtained by AVCO. The section is subdivided into three parts. The first part includes a brief description of the modified experimental test facility. The second part describes the criteria for selecting the test parameters and the set of test conditions investigated. The results of the tests are presented and discussed in the third part.

2.1 DESCRIPTION OF THE EXPERIMENTAL FACILITY

The 100-kW facility at AVCO comprises a PDU-scale, DC operated, rotating-arc reactor with the necessary measurement, control and diagnostic devices to allow a parametric evaluation of the process.

The PDU facility designed earlier for coal feed was modified to accommodate for natural gas feed. Figure 2-1 is a schematic diagram of the electric-arc reactor.

The feed gas is introduced into the reactor where it is rapidly heated to the reaction temperature (1600-1800°C) by direct contact with the rotating electric arc. The arc is rotated by a surrounding magnetic field.

The residence time of the gases in the reaction zone is in the order of milliseconds. The hot product gas stream leaving the arc zone passes through a primary quench zone where it is mixed with the incoming cold quench stream to bring down the temperature. The cooler effluent is then further quenched with water to stabilize the acetylene formed.

The reactor effluents containing a mixture of acetylene, ethylene, hydrogen, and carbon black are removed through a vacuum pump, analyzed, and then exhausted through an external stack where it is burned as it vents to atmosphere.

Other features and subsystems of the 100-kW PDU are described below:

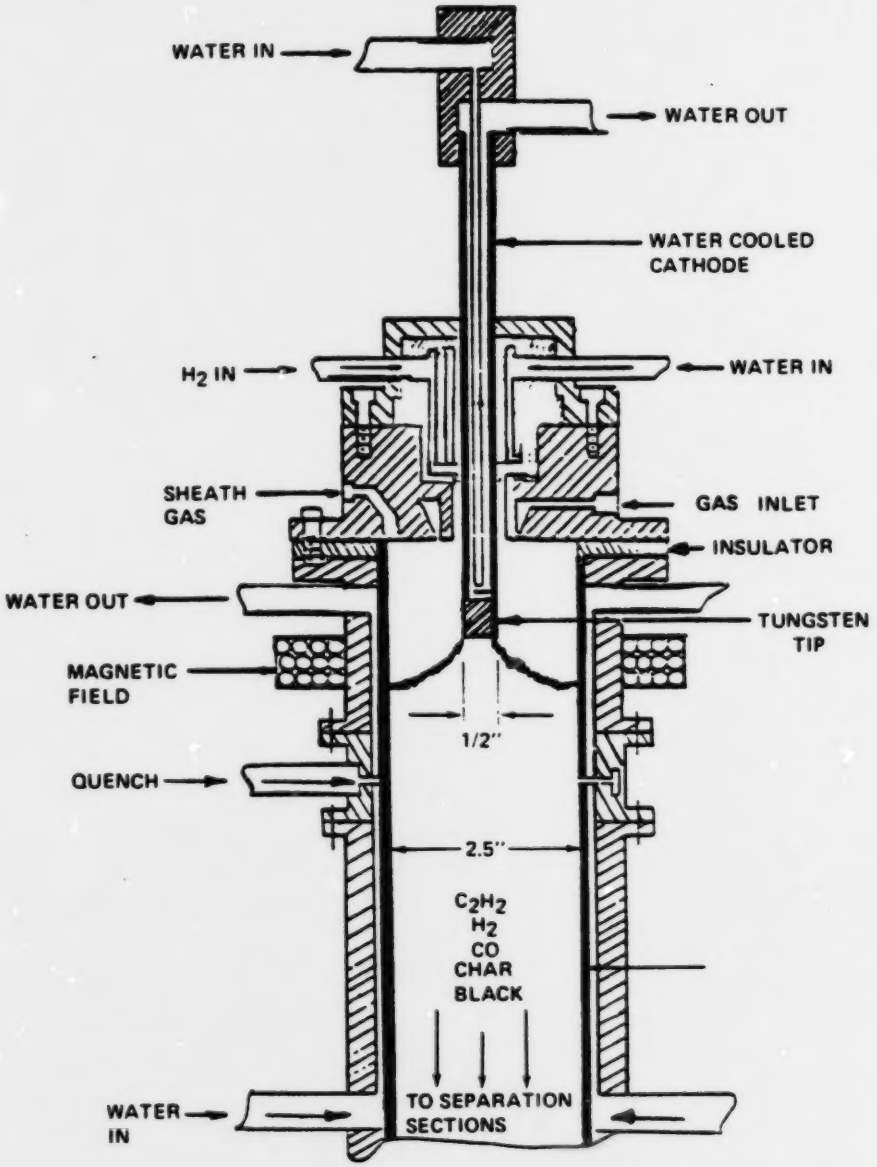

Figure 2-1 Schematic Diagram of AVCO 100-kW Electric-Arc Reactor

1 inch = 2.54 cm

2.1 DESCRIPTION OF THE EXPERIMENTAL FACILITY (Cont'd)

2.1.1 Electric-Arc Reactor

As shown in the Figure 2-1, the electric-arc reactor consists of a cathode, a cathode housing, a magnetic field coil, and an arc extension. Except the insulators within the arc-heater assembly, all the components of the reactor are water cooled.

Gas feed to the arc reactor occurs at several locations. The main gas feed entrance is through the cathode sheath injection ports; the balance of the gas is introduced through a second set of concentric injection ports located at the rear wall of the anode. If required, the feed gas may also be injected through the quench ports located downstream of the reactor anode.

The reactor is provided with a water-cooled magnetic field coil which causes the arc to rotate and spread over a larger area to distribute the heat and to prevent arc burn-out problems.

Power to the magnetic field coil is supplied by a Miller DC welder power supply. An oscillator is used to initiate the arc with a high-voltage radio frequency discharge across the electrodes.

2.1.2 Power Supply

The DC power for the arc reactor is provided by a Perkin DC rectifier with a rated output of 500 kW. Arc current is determined by measuring the voltage drop across a calibrated shunt connected in series with a volt meter connected across the cathode.

2.1 DESCRIPTION OF THE EXPERIMENTAL FACILITY (Cont'd)

2.1.3 Gas Feeding System

The reactor is equipped with three gas feed lines, two of which may be used for methane and/or hydrogen. The third one is for nitrogen which is used as an inert gas during the start-up and shutdown operations to purge the system. Nitrogen is also used in the dome-type flow regulators in all the three gas feed lines.

2.1.4 Gas Sampling and Analyses

The product gas leaving the water quench system is initially filtered to remove particulate matter larger than 0.3 microns. The filtered gas is then sampled and analyzed in a gas chromatograph to determine the concentration of acetylene, ethylene, hydrogen, methane and ethane.

A total of six samples may be withdrawn from a single test run. Since, hydrogen gives a non-linear response to the thermal conductivity detector in the GC, it's concentration was determined by difference.

2.1.5 Product Gas Disposal

After sampling, the reactor effluent is vented to the atmosphere through a roof-mounted 122-cm diameter stack equipped with a propane ignited flare system. The pilot flame is obtained from a rectification-type pilot burner which incorporates a pilot nozzle with alloy grounding fins, spark plug, flame rod, propane gas regulator and an air mixing chamber.

2.1 DESCRIPTION OF THE EXPERIMENTAL FACILITY (Cont'd)

2.1.5 Product Gas Disposal (Cont'd)

Spark ignition of the premixed propane-air stream entering the pilot burner is obtained from an ignition transformer which is activated by a Protection Controls Ignition System, Model No. 76057-B.

2.1.6 Reactor Safety Systems

The PDU is equipped with all the necessary reactor safety systems against fire, health and environmental hazards. These include combustible gas detectors, alarm system, process stream monitors for air leakage into the unit, and automatic reactor shutdown systems.

The reactor room is safeguarded with positive ventilation and explosion-proof electrical system. Interlocking process control strategy ensures that the safety criteria are satisfied prior to the introduction of combustible gases into the reactor.

2.2 PARAMETRIC STUDY OF ARC-ACETYLENE PRODUCTION WITH DIFFERENT QUENCH MEDIUMS

The principle process variables which have significant influence on the product yields, composition of the product gas, and the reactor's specific energy requirement are the flowrate and composition of the feed gas, reactor pressure, temperature, type and flowrate of the quenchants, and the quench injection point.

Thirty three experimental tests were performed with two types of feed gas (methane or methane/hydrogen mixture) and three types of quenches (hydrogen, methane or ethane) under selected range of operating conditions shown in Table 2-1.

The objective was to determine operating conditions so as to optimize the desired product yields (Y) and concentration (C), and the reactor specific energy requirement (SER). The following definitions were used:

Y_1 = (carbon in C_2H_2) / (carbon in feed)
Y_2 = (carbon in C_2H_2 and C_2H_4) / (carbon in feed and quench)

C_1 = vol% of acetylene in the product gas
C_2 = vol% of acetylene and ethylene in the product gas

SER_1 = (power input, kWh) / (kg of acetylene produced)
SER_2 = (power input, kWh) / (kg of acetylene and ethylene)

The results of the tests are summarized below while the experimental procedure is described in detail in Appendix B.

2.2 PARAMETRIC STUDY OF ARC-ACETYLENE PRODUCTION WITH DIFFERENT QUENCH MEDIUMS (Cont'd)

2.2.1 Effect of Feed Gas Flowrate

Tests No. 1-5 were made using methane as a feed gas and hydrogen as a quench. The CH_4 flowrate was varied from 4.5-9.8 l/s (10-22 scfm) while the hydrogen quench rate was held constant at about 14 l/s (32 scfm). The pressure and the arc current was also maintained at a relatively constant value in the range of 13-17 kPa (100-130 mm Hg) and 300 A, respectively.

The results indicate that when hydrogen is used as a quench, the main product formed is acetylene; negligible ethylene is formed. Figure 2-2, reproduced from the AVCO report (Appendix B), shows the effect of flowrate and composition of the feed gas on C_1, Y_1, and the SER_1 values.

The SER_1 values dropped significantly with the increase in the CH_4 flowrate from 4.5-6.3 l/s (10-14 scfm). However, at higher feedrates, the SER_1 values are nearly constant in the narrow range of 8.5-8.8 kWh/kg of acetylene formed. High acetylene yield and maximum concentration is obtained between 8-8.5 l/s (18-19 scfm). The optimum feedrate was determined as 8.3 l/s (18.7 scfm).

2.2.2 Effect of Feed Gas Composition

To study the effect of feed gas composition, six experiments were made (Tests No. 12-17) at different operating conditions using 80:20 molar mixture of CH_4 and H_2.

Table 2-1 Test Matrix for Arc-Acetylene from Natural Gas

Test No.	Feed		Quench		Arc Current (A)	Reactor Pressure (mm Hg)
	Type	Flowrate (scfm)	Type	Flowrate (scfm)		
1	CH_4	10.4	H_2	32	300	101
2	CH_4	13.0	H_2	32	300	110
3	CH_4	13.9	H_2	32	300	118
4	CH_4	18.7	H_2	32	300	126
5	CH_4	22.0	H_2	32	300	133
6	CH_4	18.7	H_2	34.8	300	120
7	CH_4	18.7	H_2	24.9	300	113
8	CH_4	18.7	H_2	15.2	300	105
9	CH_4	18.7	H_2	0	300	92
10	CH_4	18.7	H_2	33.2	300	212
11	CH_4	18.7	H_2	33.2	300	330
12	$CH_4 + H_2$	17.5	H_2	33.2	300	65
13	$CH_4 + H_2$	23.1	H_2	33.2	300	125
14	$CH_4 + H_2$	27.4	H_2	33.2	300	135
15	$CH_4 + H_2$	30.9	H_2	33.2	300	143
16	$CH_4 + H_2$	27.4	H_2	33.2	300	215
17	$CH_4 + H_2$	27.4	H_2	33.2	300	300
18	CH_4	13.8	CH_4	5.2	300	80
19	CH_4	18.7	CH_4	5.2	300	90
20	CH_4	18.7	CH_4	10.4	300	100
21	CH_4	18.7	CH_4	15.5	300	106
22	CH_4	18.7	C_2H_6	5.04	300	93
23	CH_4	18.7	C_2H_6	7.92	300	100
24	CH_4	18.7	C_2H_6	5.04	300	200
25	CH_4	18.7	C_2H_6	7.92	300	215
26	CH_4	18.7	C_2H_6	5.04	300	300
27	CH_4	18.7	C_2H_6	7.92	300	300
28*	CH_4	18.7	C_2H_6	5.04	300	92
29*	CH_4	18.7	C_2H_6	7.92	300	100
30*	CH_4	18.7	C_2H_6	5.04	300	205
31*	CH_4	18.7	C_2H_6	7.92	300	210
32*	CH_4	18.7	C_2H_6	5.04	300	330
33*	CH_4	18.7	C_2H_6	7.92	300	315

* short anode runs

Conversion to SI units:
scfm = 0.4468 l/s
mm Hg = 0.1333 kPa

2.2 PARAMETRIC STUDY OF ARC-ACETYLENE PRODUCTION WITH DIFFERENT QUENCH MEDIUMS (Cont'd)

2.2.2 Effect of Feed Gas Composition (Cont'd)

The results of the runs with CH_4/H_2 feed are shown by the solid curves in Figure 2-2. Runs made with CH_4/H_2 feed gave higher SERs and lower product yields compared to those with CH_4 feed alone.

2.2.3 Effect of Hydrogen Quench Flowrate

Tests No. 6-9 were made at an optimum CH_4 feedrate of 8.3 l/s (18.7 scfm) but hydrogen quench rate was varied between 0-15.5 l/s (0-35 scfm) at a nominal pressure range of 12-16 kPa (90-120 mm Hg). Tests No. 10 and 11 were made a higher pressures and the results are discussed in Section 2.2.6.

Figure 2-3 shows the effect of hydrogen quench flowrate on C_1, Y_1 and the SER_1 values. At zero quench rate, the concentration of acetylene is about 13 vol%, acetylene yield is 50 wt%, and the SER_1 is 9 kWh/kg of acetylene formed. The use of hydrogen quench has a positive impact on the product yield and SER values, but reduces the concentration of acetylene, as expected, due to dilution of the product gas stream.

In Figure 2-3, at hydrogen flowrate of 6.7 l/s (15 scfm), the SER is minimum, about 8.6 kWh/kg of acetylene. Increasing the flowrate beyond 6.7 l/s has negligible impact on the acetylene yield and adds only to dilution of the product gas stream. For the conditions investigated, the optimum hydrogen quench rate appears to be 6.7 l/s (15 scfm).

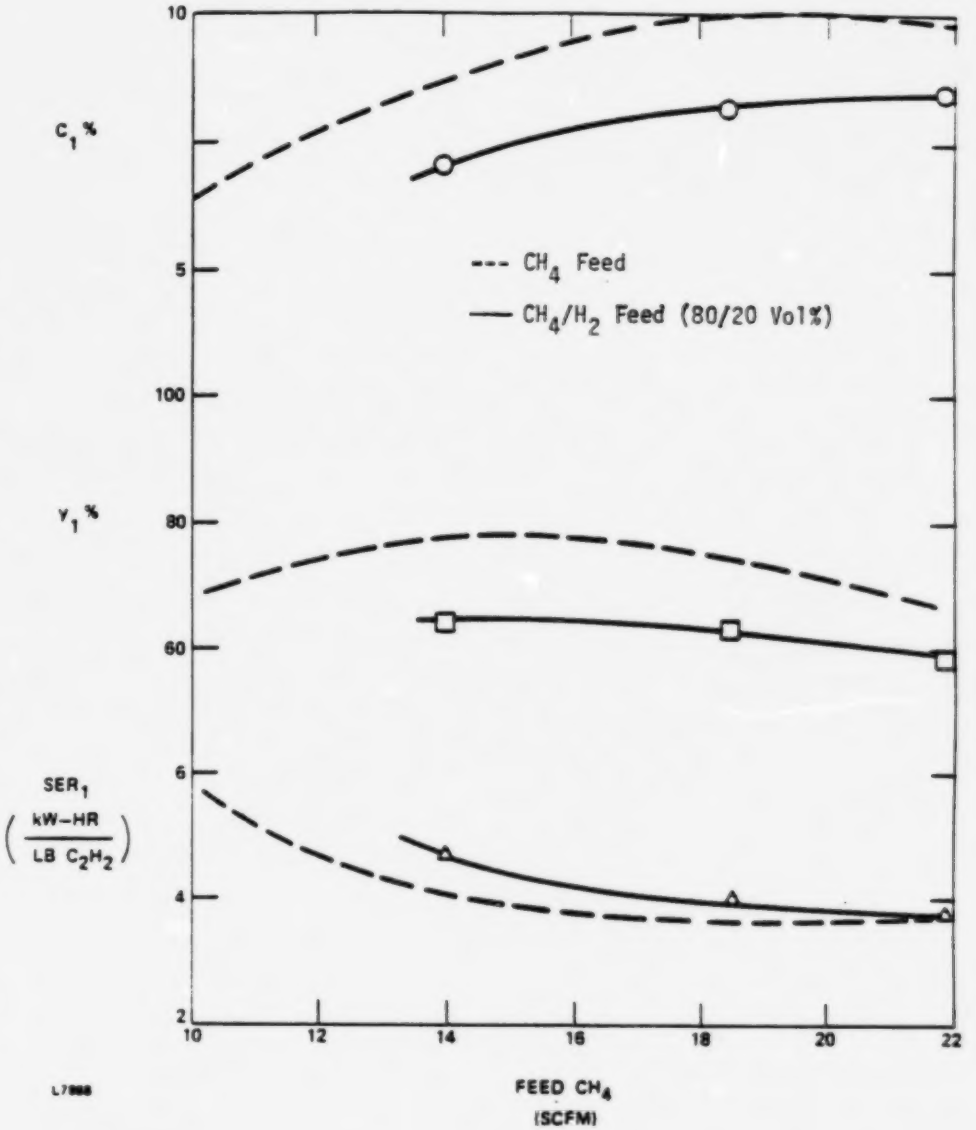

Figure 2-2 Effect of Flowrate and Composition of the Feed Gas

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Conversion to SI units
- scfm = 0.4468 l/s; mm Hg = 0.1333 kPa
- to obtain SER in kWh/kg of C_2H_2, multiply the values shown by 2.204

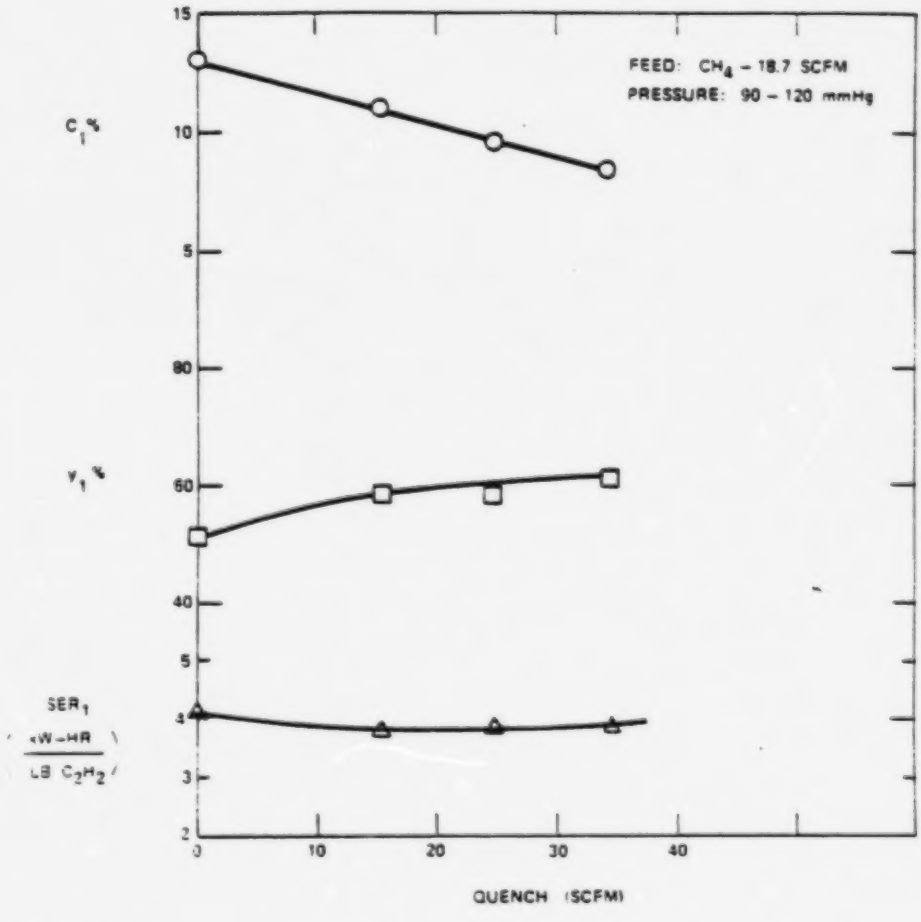


Figure 2-3 Effect of Hydrogen Quench Flowrate

Conversion to SI units
- scfm = 0.4468 l/s; mm Hg = 0.1333 kPa
- to obtain SER in kWh/kg of C_2H_2, multiply the values shown by 2.204

2.2 PARAMETRIC STUDY OF ARC-ACETYLENE PRODUCTION WITH DIFFERENT QUENCH MEDIUMS (Cont'd)

2.2.4 Runs with Methane and Ethane as a Quench

Tests No. 18-21 were made with CH_4 as a feed and also as a quench. Subsequent runs (Tests No. 22-27) were carried out with ethane as a quench. In both cases, the CH_4 feedrate was maintained at an optimum value of 8.3 l/s (18.7 scfm) whereas the methane quench rate was varied from 2.3-6.9 l/s (5.2-15.2 scfm) and ethane flowrate between 2.2-3.5 l/s (5-7.9 scfm).

The results are shown graphically in Figure 2-4. It may be seen that the CH_4 quench runs gave poorer acetylene yields and higher SER compared with ethane and hydrogen quenches. In fact, the results of the runs with CH_4 quench are nearly the same as Test No. 9 made with no quench. Therefore, addition of CH_4 as a quench does not have any positive impact on the product yields and the SER. This is probably because methane requires temperature in excess of 1200°C for significant conversion to either acetylene or ethylene; consequently it appears that the temperature in the quench zone is lower than 1200°C.

From the product gas composition analysis given in Appendix B (see Tables 3-3, 3-5, and 3-6), it may be observed that when hydrogen or methane is used as a quench, the main product is acetylene; negligible ethylene is formed. With ethane, substantial amount of ethylene is produced (upto 0.28 kg/kg of acetylene). Ethane not only acts as a quench but also takes part in the reaction.

2.2 PARAMETRIC STUDY OF ARC-ACETYLENE PRODUCTION WITH DIFFERENT QUENCH MEDIUMS (Cont'd)

2.2.5 Effect of Location of Quench Injection Point

Since, ethane reacts mainly to form ethylene in the temperature range of 900-1200°C, subsequent runs (Tests No. 28-33) were made at reduced primary quench length, i.e., the distance between the arc strike point (anode) and the quench injection port. The primary quench distance of 15 cm was reduced to 7.5 cm, thereby allowing ethane to be introduced closer to the arc zone.

Runs were made with optimum CH_4 feedrate of 8.3 l/s at ethane quench rates of 2.2 and 3.5 l/s, or 5 and 7.9 scfm. Typical results at lower ethane quench rate of 2.2 l/s (5 scfm) are shown in Figure 2-5.

While there is no significant improvement in acetylene yield (Y_1) and SER_1 value, the overall product yield (Y_2) is about 10% higher, and the SER_2 about 10% lower confirming that additional ethylene is formed during quenching when ethane is introduced closer to the arc zone.

2.2.6 Effect of Pressure

The effect of pressure was determined by maintaining the feed gas and quench flowrates constant and varying the system pressure.

Results with CH_4 feed and hydrogen quench are presented in Figure 2-6. The SER_1 value changes marginally with increase in pressure but has a minimum value at about 27 kPa (200 mm Hg). The effect is, however, more pronounced for the ethane quench case shown earlier in Figure 2-5. Maximum product yields and concentrations, and lower SERs are in the optimum pressure range of 25-35 kPa (190-260 mm Hg).

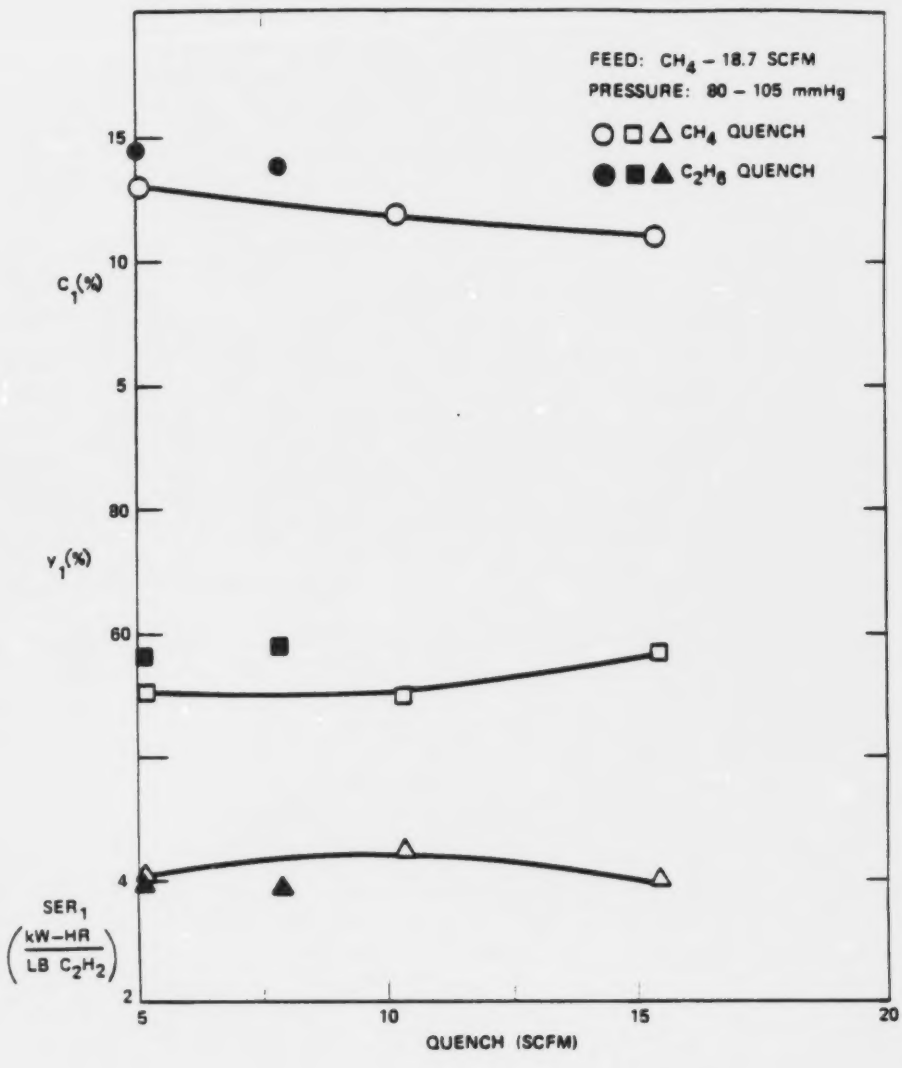


Figure 2-4 Effect of Flowrate of Methane and Ethane Quenches

Conversion to SI units
- scfm = 0.4468 l/s; mm Hg = 0.1333 kPa
- to obtain SER in kWh/kg of C_2H_2, multiply the values shown by 2.204

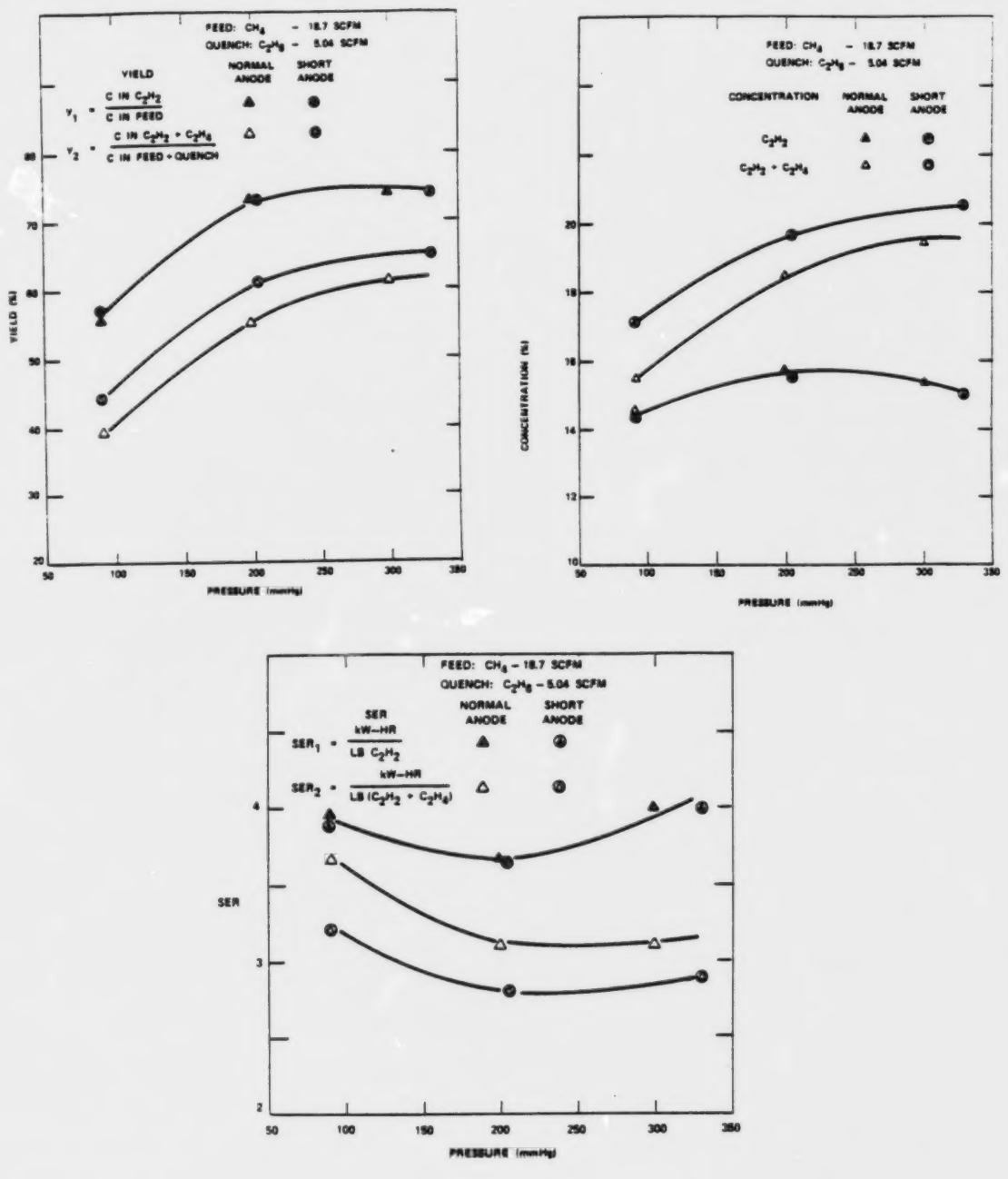


Figure 2-5 Effect of Location of Quench Injection Point

Conversion to SI units
- scfm = 0.4468 1/s; mm Hg = 0.1333 kPa
- to obtain SER in kWh/kg of C_2H_2, multiply the values shown by 2.204

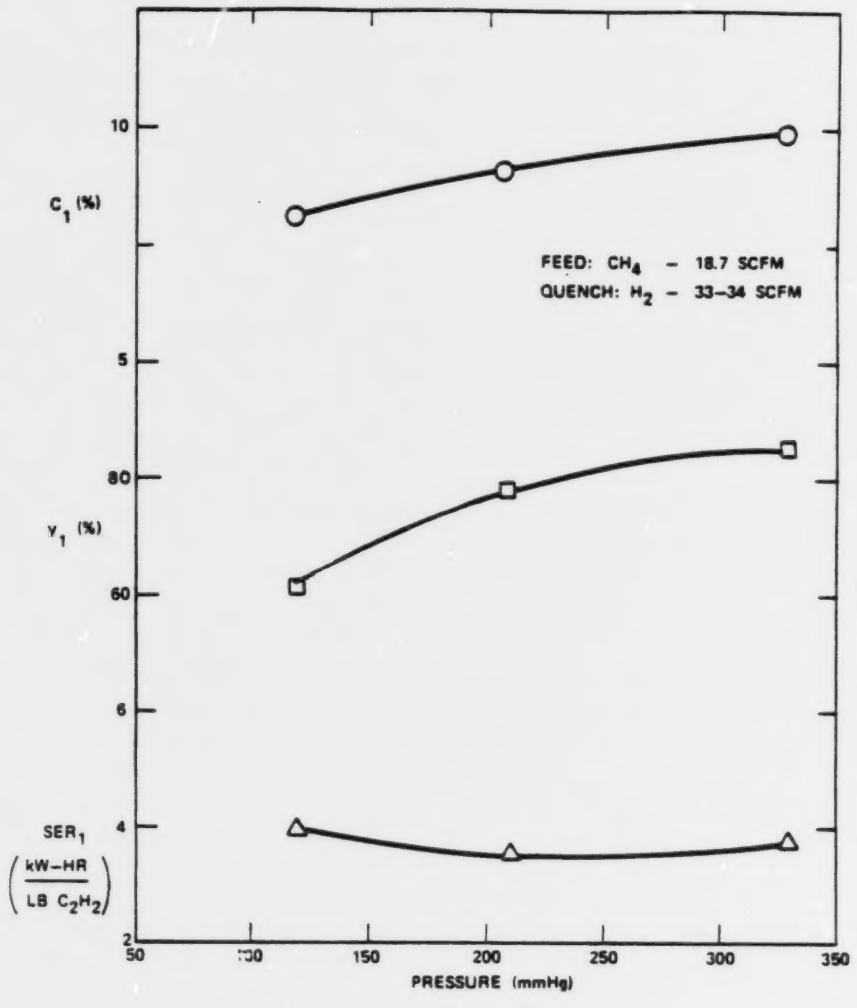


Figure 2-6 Effect of Pressure

1 inch = 2.54 cm

2.2 PARAMETRIC STUDY OF ARC-ACETYLENE PRODUCTION WITH DIFFERENT QUENCH MEDIUMS (Cont'd)

2.2.7 Arc-Reactor Scale-up and Process Design Parameters

Based on 100-kW PDU experiments and tests made earlier by AVCO on 1-MW pilot plant unit, reactor scale-up predictions were made by AVCO for the following cases; details of which are given in Appendix B:

Power Input		5 MW		8 MW	
Arc Voltage	V	2500	5000	4000	8000
Arc Current	A	2000	1000	2000	1000
Reactor Pressure	kPa	50	50	50	100
Reactor Diameter	m	0.8	1.3	1.4	1.2

For the hydrogen quench option, at the reactor operating pressure of 50-100 kPa, AVCO predicted the following key parameters:

Concentration of C_2H_2 (C_1) : 10 vol%
Acetylene yield (Y_1) : 90 wt%
Specific Energy Requirement (SER_1) : 7.7 kWh/kg of C_2H_2

Similarly, for the ethane quench,

Concentration of C_2H_2 and C_2H_4 (C_2) : 20 vol%
Acetylene and ethylene yields (Y_2) : 90 wt%
Specific Energy Requirement (SER_2) : 5.5 kWh/kg of $C_2H_2 + C_2H_4$

These values were taken as the design basis for the conceptual, commercial plant configuration described in the following section.

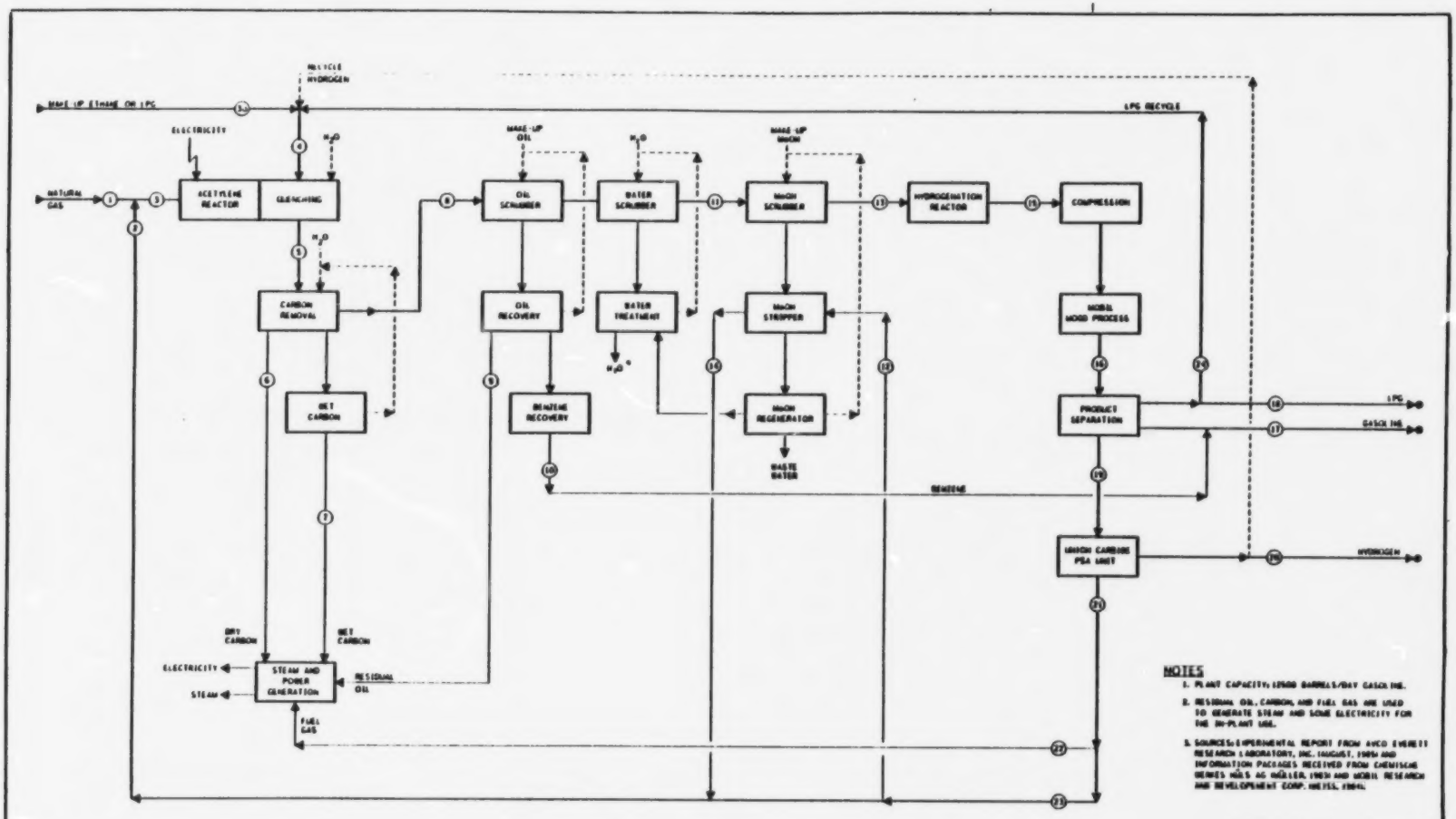
3.0 OVERALL PLANT CONFIGURATION

3.0 OVERALL PLANT CONFIGURATION

The overall configuration of a commercial-scale liquid fuel plant is presented in this section. The design capacity of the conceptual plant is 12 500 bbl/d of gasoline produced from acetylene obtained in the electric-arc reactors. The overall configuration includes the acetylene plant, catalytic hydrogenation, olefin oligomerization and hydrogen recovery units along with the required support systems, utility and offsite facilities to comprise an integrated, self-sufficient operation.

Natural gas, ethane or LPG and electricity are the basic raw materials and process input, whereas hydrogen, ethane, or LPG could be used as cold quench medium to stabilize the intermediate acetylene formed and also to recover part of the process heat. Make-up water, catalysts and other chemicals are also needed but in relatively smaller quantities. During steady-state operation, steam is generated by recovering process heat and by burning fuel gas, residual oil and the carbon formed in the acetylene reactors. Excess fuel gas is used to generate part of the electricity required by the plant.

The utility services include a full range of systems for a self-sufficient integrated operation of the plant such as steam generation, electricity and fuel gas distribution, cooling water, instrument air, boiler feedwater treatment, potable water, fire water, storm and waste water facilities. Offsite requirements include items such as administration buildings, laboratory, maintenance buildings, warehouses, firehouse, in-plant road, fence, flares, product storage, etc.



NOTES

1. PLANT CAPACITY: 10500 BARRELS/DAY GASOLINE.
2. RESIDUAL OIL, CARBON, AND FUEL GAS ARE USED TO GENERATE STEAM AND SOME ELECTRICITY FOR THE IN-PLANT USE.
3. SOURCES: EXPERIMENTAL REPORT FROM AVCO EVERETT RESEARCH LABORATORY, INC. (AUGUST, 1989) AND INFORMATION PACKAGES RECEIVED FROM CHEMISCHE WERKE HÜLS AG (HÜLLER, 1989) AND MOBIL RESEARCH AND DEVELOPMENT CORP. (WEISS, 1984).

STREAM NO	1	2	3	3a	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
STREAM DESCRIPTION FLOWRATE kg/h	NATURAL GAS	RECYCLE GAS	TOTAL FEED	MAKE-UP ETHANE OR LPG	QUENCH	REACTOR EFFLUENT	DRY CARBON	WET CARBON	GAS TO PRODUCT RECOVERY	RESIDUAL OIL	BENZENE	GAS TO NMP SCRUBBER	STRIPPING GAS	GAS TO HYDROGEN PSA UNIT	RECYCLE GAS TO REACTOR	OLEFIN RICH FEED	MOBIL REACTOR OUTLET	GASOLINE PRODUCT	LPG BY-PRODUCT	OFF GAS	HYDROGEN BY-PRODUCT	RECYCLE GAS	FUEL GAS	RECYCLE GAS TO REACTOR	LPG RECYCLE
ETHANE QUENCH	56439	10152	74571	35520	35520	110491	2308	1153	107699	500	250	108061	8733	99268	10152	99268	99268	60768	12968	25760	9860	16200	6647	8733	0
HYDROGEN QUENCH	95291	21704	116995	0	15252	132747	2976	1487	129646	645	310	129833	13673	120784	21704	120784	120784	60699	14464	45734	11863	16777	5604	13673	0
LPG QUENCH	73605	22639	96224	12129	30706	126950	2974	1462	123411	2048	638	121333	12209	110333	22639	110335	110335	60977	0	51420	8268	22152	9943	12209	10877

SNC Inc.

CANMET

BENCH SCALE & BENCHMARK, CANADA

GASOLINE PRODUCTION FROM METHANE GAS VIA ELECTRIC ARC REACTOR

OVERALL BLOCK FLOW DIAGRAM OF A CONCEPTUAL COMMERCIAL PLANT USING SAME GASOLINE PROCESS

CONTRACT 1,3,6,6

3.0 OVERALL PLANT CONFIGURATION (Cont'd)

Three different options are considered for the production of acetylene in the electric-arc reactor process, namely the hydrogen quench, ethane quench and the LPG quench.

Pertinent process design and reactor scale-up data were obtained experimentally on the 100-kW electric-arc reactor at AVCO Everett Research Laboratories using the hydrogen and the ethane quench systems (see Section 2.0 and Appendix B). The operating condition for the hydrogen quench option was based on the Test No. 8, while the data gathered in Test No. 30 was used for the ethane quench case.

For the LPG quench alternative, experimental data for a no-quench base run (Test No. 9) was used in conjunction with information provided by Chemische Werke Hüls [Müller 1983].

The detailed material and energy balances for each of the three process alternatives are tabulated in the Appendix C. The product yield, efficiencies and utility requirements are summarized later in this section.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION

The overall block diagram showing the interrelationship between the various processing areas for an integrated acetylene-based liquid fuel plant is shown in Figure 3-1. The main processing areas may be sub-divided as:

- Acetylene Reactor/Quenching
- Gas Purification and Primary Product Separation
- Acetylene Hydrogenation

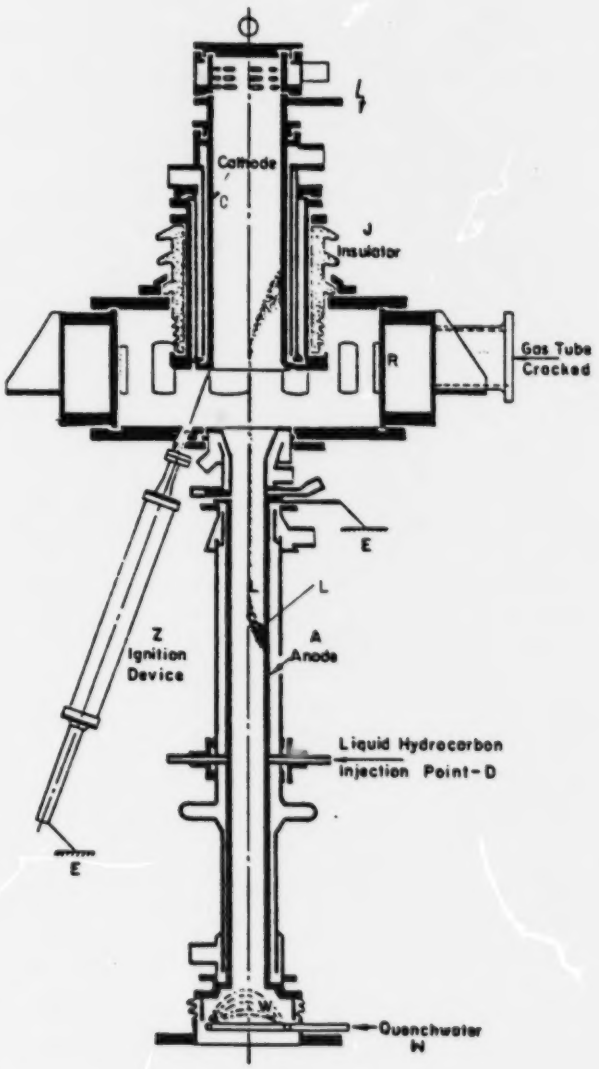


Figure 3-2 Schematic Diagram of the Huels Electric-Arc Reactor

Source: Muller, R. Chemische Werke Hüls, Information Package prepared for SNC Inc., Ref 1050/08/Bu, December 23, 1983

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

- Mobil Olefin to Gasoline and Diesel (MOGD) process
- Pressure Swing Adsorption (PSA) Unit for Hydrogen Recovery

The overall block diagram shown in Figure 3-1 is for a typical liquid-fuels-via-acetylene plant and includes all the three process options considered in this study. The flowrates of major streams are also given in Figure 3-1.

The salient features of each of the process options including a summary of material, energy, and utility balances are presented below.

3.1.1 Arc-Acetylene Reactor System

Several electric-arc acetylene reactor systems are in development stage but the only one in commercial operation today is at Chemische Werke Hüls in Germany. Chemische Werke is operating 19 commercial reactors (9 MW each) in a peak shaving mode to produce about 120 000 t/yr acetylene, 50 000 t/yr ethylene and 500 million Nm^3/yr hydrogen as a byproduct. The acetylene produced is used for vinyl chloride monomer, butanediol and trichlorethylene production.

Figure 3-2 is a recent design of the Hüls electric-arc reactor. The gaseous feedstock enters the reactor tangentially through a turbulance swirl chamber R (700-800 mm diameter, 300-500 mm high) and passes with a rotary motion through the reaction zone A (diameter 85-105 mm, length approximately 1.5 m). The swirling motion of the downward flowing gas stream stabilizes the arc by essentially preventing upward convective movement of the hot

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.1 Arc-Acetylene Reactor System (cont'd)

gases which tend to break (or destabilize) the arc. Other process developers such as Dupont [Burk 1959], Westinghouse [Fey 1980], and AVCO [Wragg 1980] have opted to "rotate" the arc at high speed instead with the surrounding magnetic field. Since these systems are not commercially available, they are not described here.

The arc L burns between the bell-shaped cathode C and the tubular anode A (grounded at E). Both electrodes are hollow and are water-cooled. The striking point of the arc in the anode and/or cathode can be moved upward or downward, as required, and as such the arc is termed by Hüls as "elastically suspended". The wall thickness of the electrodes is 10-20 mm. With the exception of the insulator J all parts of the reactor are made of iron.

The arc is about 100 cm long and extends 40-50 cm into the anode. During the start-up operation, starting of the arc is achieved by an ignition electrode Z. The arc is operated with 8000 kW direct current at 7000 Volts and a current of 1150 Amperes. The power factor is nearly 0.75 and longitudinal field intensity is 70 V/cm.

Power Supply

The electric-arc is operated with DC primarily due to difficulties associated with normal AC. The DC is furnished by a grid-controlled mercury rectifier. Each reactor has its own adjustable DC supply for ease of regulation. The time constant of the regulating circuit is only a few milliseconds.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.1 Arc-Acetylene Reactor System (Cont'd)

In spite of the high voltage (about 7000 volts), no operational difficulties are encountered with the rectifiers, control devices and the electric-arc ignition devices. Operating time of 50 000 hours, sometimes extending to 100 000 hours have been realized in commercial operation.

Electrodes

The carbon black produced deposits on the electrodes to form hard graphite which affect the stability of the arc. Cathodes are normally replaced every 800 hours and anodes after about 200 hours of operation. The replacement time of electrodes is only few hours, however, to prevent disruption in production, spare electric-arc reactors are provided.

Gas Flow and Temperature

As shown in Figure 3-1, natural gas mixed with recycle gas is fed into several arc reactors. For normal operatoin, 45 reactors each of 9 MW capacity, excluding spares, are required. The feedrate per reactor is about 1660 kg/hr of feed or the energy requirement is about 5.4 kWh/kg of feed.

Desired reaction temperature is 1800°C. Typically, the feed gas passes through the arc at about 1000 m/s and the residence time is in the order of 2 ms.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.1 Arc-Acetylene Reactor System (Cont'd)

Gas Flow and Temperature

The temperature of the arc itself is in the range of 18 000 to 20 000°C. On the other hand, the temperature of the inner wall of the water-cooled anode is about 500°C, therefore a steep radial temperature gradient exists in the arc zone. However, rapid heat transfer and high energy transmission per cm of arc length is achieved mainly due to high temperature of the electric-arc itself and high diffusion velocities and thermal conductivity of the hydrogen atoms and ions formed which rapidly transfer dissociation, ionization and excitation energy to other reacting species.

3.1.2 Quenching with Ethane

The hot gases containing mainly acetylene, hydrogen, C_3/C_4 acetylenes, dienes, unreacted methane and some carbon monoxide leaving the arc zone have substantial energy because of its high temperature (about 1500°C). About 20 cm below the anode A, the quench stream is introduced into the reactor through several nozzles D to cool the product gas to 800-1000°C and stabilize the acetylene formed. The cold ethane quench is mainly converted to ethylene. The exiting hot reaction mixture is further cooled to about 200-250°C by means of a water spray W. The residence time during quenching is less than 2 ms.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.2 Quenching with Ethane (Cont'd)

The composition and flowrate of the reactor effluent stream, after quenching, are as follows:

	kg/h	mol %
C_2H_2*	41 866	15.1
C_2H_4	31 687	10.6
C_3/C_4 acetylenes and dienes	4 265	0.7
C_3H_6	863	0.2
C_4H_8	165	-
C_5H_6/C_6H_6	836	0.1
CH_4	4 107	2.4
C_2H_6	4 066	1.3
C_3H_8/C_4H_{10}	738	0.2
Higher hydrocarbons	320	-
H_2	14 252	66.2
CO	1 574	0.5
N_2	3 344	1.1
HCN	5	45 ppm
Carbon	2 403	1.6
TOTAL	110 491	100.0

*acetylene formed in the arc zone = acetylene in the product stream
- acetylene in recycle feed
- acetylene formed during quenching

= 41 866 - 3982 - 1113 = 36771 kg/h

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.2 Quenching with Ethane (Cont'd)

The reactor's specific energy requirement is about 10.4 kWh/kg of acetylene formed.

On a carbon-free basis, acetylene concentration in the product gas stream is about 15.3%. The existing gas stream undergoes a series of gas processing and product separation steps as described below.

3.1.3 Gas Purification and Primary Product Separation

The separation and processing of acetylene containing gas stream imposes certain restrictions and limitations due to the unstable and explosive behaviour of acetylene. Extensive physical data has been generated over the years concerning conditions which will decompose, explode or detonate acetylene. Also, experimental tests have been well documented by Miller [1966], Copenhaver and Bigeloro [1949] and by Kirk and Othmer [1964].

The results of decomposition and detonation studies on acetylene and its mixture with other gases indicate that operating conditions where the partial pressure of acetylene exceed 200 kPa (30 psi) should be avoided for safe operation. However, under special care acetylene has been transported and handled over long distances at pressures of several atmospheres [Copenhaver and Bigeloro 1949]. Similar limitations apply to operating temperatures which should not exceed 95-105°C. On the other hand, low temperatures lead to formation of liquid or solid-like acetylene and its homologs. The separation and purification of acetylene

3.1.3 **Gas Purification and Primary Product Separation** (Cont'd)

is further complicated by the presence of higher acetylenes which tend to polymerize easily.

In view of these severe operating restrictions a few commercial processes are available [Miller 1966, Tedeschi 1982] based on absorption-desorption techniques with one or more selective solvents namely anhydrous ammonia (SBA), cold methanol (Montecatini process), n-methylpyrrolidinone (BASF), di-methyl formamide (Dupont process), and water as in the original Hüls process. At present, a modern separation process developed jointly by Hüls and Linde AG [Kruis 1967] is in operation which is described below.

As shown in Figure 3-1, most of the carbon black is initially removed from the product gas stream as dry carbon (about 4 wt% H_2O, 5 wt% hydrocarbons) by a series of cyclone separators. The balance is rejected as wet carbon (50 wt% H_2O, 22.5 wt% hydrocarbons) in a water spray towers. The wet carbon black is then sent to the horizontal filters to reject excess water. Both dry carbon and wet carbon filter cake is used as a fuel to generate steam for the process.

The solid-free gas (containing less than 3mg carbon/m^3 of gas) is treated in an oil venturi and scrubber to remove naphthalenes and other hydrocarbons. Benzene is further recovered as a byproduct by distillation and blended with gasoline. The gas stream is then treated in a water scrubber to remove traces of hydrocyanic acid.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.3 Gas Purification and Primary Product Separation (Cont'd)

The effluent gas is compressed to 1.5 MPa in four-stage reciprocating compressors and then treated in methanol scrubbers operating at 30°C to separate C_3/C_4 dienes and higher acetylenes before being recycled to the reactor.

The remaining gas stream is heated to about 150°C prior to feeding into the catalytic hydrogenation unit.

3.1.4 Acetylene Hydrogenation

Acetylene present in the gas stream is hydrogenated to olefins (mainly ethylene) since suitable processes for liquid fuel production are based mostly on olefin oligomerization rather than acetylene polymerization [Cooke and Ashraf 1984]. Also, acetylene polymerization processes are either at a developing stage [Allenger et al 1984] or have rapid catalyst deactivation problems [Tsai and Anderson, 1983].

Selective hydrogenation of acetylene to ethylene is carried out "in-situ" over Pd based catalyst at 150-175°C and 1.4 MPa using hydrogen present in the gas stream. Other typical catalysts include platinum, nickel and cobalt [Spiers 1963]. An extensive review on acetylene hydrogenation is described elsewhere [Miller 1966].

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.4 Acetylene Hydrogenation (Cont'd)

The conversion of acetylene to ethylene is highly exothermic (-175 kJ/gm-mole). Other side reactions which also take place are conversion of olefins such as ethylene, propylene, and butylene to saturated hydrocarbons. Excess heat is used to preheat the exiting olefin-rich stream to 150°C and to generate steam for the process.

Some carbon deposition takes place on the catalyst and typically requires regeneration every six months. This is achieved by conventional steam/air decoking operation at 550°C. An auxiliary furnace is used to preheat the air and supply heat. The catalyst life is about 3-4 years.

The olefin-rich stream* containing 67.5 wt% ethylene, 1.3 wt% propylene and 0.8 wt% butenes is compressed to 3.45 MPa (500 psi) and preheated to 315°C (600°F) prior to feeding into the MOGD reactor.

3.1.5 Mobil Olefin to Gasoline and Distillates (MOGD) Process

MOGD is a catalytic process developed by Mobil Research and Development Corporation for converting light olefinic compounds to high quality gasoline and/or distillates. The process is based on Mobil's synthetic zeolite catalyst (ZSM-5) which selectively oligomerizes the light olefins to the desired

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* complete stream analysis is given in Appendix C, Stream No. 15.

3.1.5 Mobil Olefin to Gasoline and Distillates (MOGD) Process (Cont'd)

product. Though normally designed to process propylene and butylene, MOGD is applicable to a wide range of feedstreams ranging from ethylene to olefinic naphtha [Tabak 1984].

The process is also flexible with respect to the final product so as to produce distillate/gasoline ratios ranging from 0/100 to 90/100. Based on the analysis of feedstream supplied by SNC to Mobil, the process developer recommended that gasoline production would be desirable [Weiss 1984]. Suggested reactor conditions are 250-315°C and pressure of 1.8-3.4 MPa. The product gasoline has high octane number (92 RON, 79 MON) and meets most of the standard specifications. Gravity is 62° API.

The reactor is highly exothermic necessitating heat control to avoid temperature runaway problems. Four fixed-bed reactors are used, three on line and one in generation. The three online reactors are in series with inter-reactor coolers and liquid recycle to control the heat. The reactor with the oldest catalyst is in the first position whereas the reactor with fresh catalyst is in the third or the last position, thus a descending temperature profile is maintained. Since high molecular weight product is thermodynamically favored by low temperature, this combination of low temperature with high activity catalyst in the last reactor is directionally consistent for maximum selectivity and conversion to the desired gasoline product.

The reactor effluent is separated into three streams by conventional flash separation and distillation methods. The offgas

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.5 Mobil Olefin to Gasoline and Distillates (MOGD) Process (Cont'd)

stream containing methane and hydrogen is sent to the Pressure Swing Adsorption (PSA) unit for byproduct hydrogen recovery. The LPG stream is taken as a byproduct. The gasoline product is blended with the byproduct benzene and sent to storage.

The flowrate and composition of the MOGD product streams are:

	Offgas		Byproduct LPG		Gasoline
Flowrate, kg/h	25 780		12 918		60 510
Composition, wt%					
H_2	38.1	C_3H_6	4.9	Gasoline	100.0
CH_4	15.9	C_3H_8/C_4H_{10}	80.4		100.0
C_2H_6	27.0	C_4H_8	14.7		
CO	6.0		100.0		
N_2	13.0				
	100.0				

3.1.6 Hydrogen Recovery Using Pressure Swing Adsorption (PSA) Unit

The offgas leaving from MOGD process at 40°C is compressed from 1.24 MPa (180 psi) to 2.4 MPa (350 psi) and fed into the Union Carbide's Polybed Pressure Swing Adsorption unit [Mori 1983]. Essentially the PSA unit is based on the principle of pressure reduction to remove adsorbed components from the molecular sieve (adsorbent) which adsorbs nearly all the components other than hydrogen from the inlet gas stream.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.6 Hydrogen Recovery Using Pressure Swing Adsorption (PSA) Unit (Cont'd)

A complete PSA system cycle consists of the following four basic steps: adsorption, depressurization, purge at low pressure, and repressurization. Typically when the reactor 1 is on the adsorption step providing high-purity hydrogen at high-pressure, adsorber 2 is in the depressurization phase providing gas for purging of adsorber 3 and the repressurization of adsorber 4. Adsorber 3 is being purged at low pressure (14 kPa) for removal of other components in the tail-gas line. Adsorber 4 is repressurized by the gas from adsorber 2, and the gas is then recovered when this vessel comes on line.

The pressure swing cycle can be accomplished by using any number of adsorbent beds. In its simplest form, only two adsorbent beds are needed; one being on adsorption while the other bed is undergoing the three steps of regeneration. The conventional two-bed system results in the lowest equipment cost but has a major disadvantage in allowing rather large unrecoverable hydrogen losses during the repressurization step. In addition, the two-bed system is limited to relatively low throughputs.

The four-bed HYSIV^{R} PSA unit minimizes hydrogen losses occuring during depressurization. However, as a general rule, use of these units is restricted to 13 400 Nm^3/h (12 MM scf/d) of hydrogen product capacity for optimum overall economics taking into consideration the equipment cost and hydrogen recovery. For higher capacities, polybed PSA units with multiple beds and optimum cycle operation for higher hydrogen recovery and lower

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.6 Hydrogen Recovery Using Pressure Swing Adsorption (PSA) Unit (Cont'd)

adsorbent inventory are advantageous. Capacities as high as 78 275 Nm^3/h (70 MM scf/d) of hydrogen can be achieved in a single train of PSA unit. For the proposed plant capacity, two trains each of 67 000 Nm^3/h (60 MM scf/d) of hydrogen capacity are required.

The recovered byproduct hydrogen leaving at about 2.3 MPa (340 psig) is about 92 wt% (99.4 mol%) pure. Impurities include 7.9 wt% nitrogen and 210 ppm carbon monoxide. Overall hydrogen recovery is about 90%.

The waste gas stream containing mainly methane, some ethane, carbon monoxide, hydrogen and nitrogen is used partly as inplant fuel (267 GJ/h). The remaining portion is used for stripping remaining alkenes after which it is recycled directly to the acetylene reactors.

3.1.7 Utilities and Offsite Facilities*

The utility services include a full range of systems necessary for the operation of the plant, such as raw water treatment, cooling water and boiler feed water, condensate treatment, steam and electricity distribution, plant and instrument air system, fuel gas purification and distribution.

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* not shown on Figure 3-1.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.7 Utilities and Offsite Facilities (Cont'd)

River water is assumed to be the source of make-up water for the plant. This water may be treated in a cold lime unit and filtered to reduce hardness, carbonate alkalinity, turbidity and suspended organics. The softened water is used directly as cooling tower make-up water and as process water. It is also supplied to the demineralization unit where cation, anion, and mixed-bed ion-exchangers are used for boiler feed water (BFW) preparation. The demineralized water is sent for deaeration and then distributed to onsite and offsite steam generators.

Waste water from the effluent control section, drained-off water from product storage areas, and contaminated rain water are collected and treated in an API separator for removal of oil before passing to the intermediate treatment section. Cooling tower blowdown water is also sent for intermediate treatment where the water is neutralized and subjected to chemical flocculation and dissolved air flotation. Part of the treated water is used as make-up for the cooling towers, and the excess passes to the outfall system. Uncontaminated rainwater is also drained to the outfall system.

All the steam requirements for the process are met by recovering process heat and by burning residual oil, carbon black and excess fuel gas. Some electricity is also generated on site.

Other offsite requirements include intermediate and final product storage, flare system, laboratories, administration buildings, warehouses, firehouse, onsite roads and shipment facilities.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.8 Overall Material and Energy Balance, Product Efficiencies and Utilities Summary

The interrelationship between various processing areas and the material balance of a conceptual, commercial, integrated liquid fuel plant is presented in Figure 3-1. The overall material balance summary is presented in Table 3-1. The utilities balance, i.e., the consumption and production of steam, fuel gas, electricity, etc., are summarized in Table 3-2.

The main product is gasoline. Hydrogen is the byproduct. Residual oil, carbon black and excess fuel gas are used to generate steam and 30 MW electricity within the plant. All the low-pressure steam required for the process (30 777 kg/h) is generated by recovering process heat from the acetylene hydrogenation unit. The excess LP steam (50 215 - 30 777 = 19 438 kg/h) is used as a feed for generating high-pressure steam.

The make-up water requirement is 910 m^3/h, or about 4000 US GPM. The large volume of this make-up water is mainly due to losses and consumption of water in cooling towers.

The "overall product" efficiency is 71.6%. The definition used in the total heating value of all products (gasoline and hydrogen) divided by the input energy of natural gas, LPG and electricity and other fuels.

The gasoline or the desired product efficiency is 43.8%.

3.1 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING ETHANE QUENCH CONFIGURATION (Cont'd)

3.1.8 Overall Material and Energy Balance, Product Efficiencies and Utilities Summary (Cont'd)

Input	Flowrate kg/h	HHV kJ/kg	Energy GJ/h
Natural Gas	56 439	52 515	2964
Ethane	35 920	50 000	1796
Scrubbing Oil	681	42 000	28.6
Methanol	341	22 150	7.6
Electricity (net)	453 MW	3 600 kg/kWh	1631
			6427

Output			
Gasoline	60 768	46 272	2812
LPG	12 918	51 400	664
Hydrogen	9 500	118 700	1128
			4604

Table 3-1 Overall Material and Energy Balance Summary for a 12 500 bbl/d Gasoline Plant using Electric-Arc Reactor with Ethane Quench

	Flowrate/Quantity	Unit Basis**** per kg of gasoline
Process Input, kg/h		
Natural Gas	56 439	0.93 kg
Ethane	35 920	0.59
Scrubbing Oil	681	-
Methanol	341	-
Purchased Electricity, MW		
Acetylene Reactor	405 MW	6.7 kWh
Plant Use	78	1.3
*Generated Onsite	(30)	(0.5)
	453	7.5 kWh
Utilities Required		
*HP Steam (2 MPa)	58 664 kg/h	0.96 kg
**LP Steam (0.4 MPa)	30 777	-
Cooling Water (t_e=26°C, Δt=10°C)	27 484 m^3/h	0.45 m^3
Make-up Water	910	0.015
Instrument Air (0.5 MPa, Dew Point = -25°C)	1 200 Nm^3/h	-
Nitrogen (0.4 MPa)	975	-
Products/Byproducts, kg/h		
Gasoline (12 500 bbl/d)	60 768	1.0 kg
Hydrogen	9 500	0.16
***LPG	12 918	0.21
*Residual Oil	509	0.008
*Carbon black (dry)	2 308	0.038
(wet)	1 153	0.019
*Fuel Gas (267 GJ/h)	6 547	4.40 MJ

* Residual oil, carbon black and fuel gas are used to generate steam and some electricity (30 MW) for the inplant use.

** LP steam requirement (30 777 kg/h) is met by steam produced (50 215 kg/h) in the acetylene hydrogenation unit. Excess LP steam (50 215 - 30 777 = 19 438 kg/h) is used for generating HP steam. See Table 3-2 for utilities summary.

*** LPG may be sold as a byproduct or used internally as a quench.

**** 1 kg of gasoline = 1.3706 litres.

Table 3-2 Utilities Summary for a 12 500 bbl/d Gasoline Plant using Electric-Arc Reactor with Ethane Quench

	Residual Oil	Carbon Black (dry)	Carbon Black (wet)	Fuel Gas	Electricity	Steam HP (2MPa)	Steam LP(0.4 MPa)	Cooling Water	Make-up H_2O	Instrument Air	Nitrogen
Process Areas	kg/h	kg/h	kg/h	GJ/h	MW	kg/h	kg/h	m^3/h	m^3/h	Nm^3/h	Nm^3/h
Acetylene Unit	-	-	-	-	405	57 159	30 777	26 378	-	700	700
Hydrogenation Unit	-	-	-	-	3	1 505	-	1 005	-	235	-
Mobil Process	-	-	-	104	27	-	-	101	-	70	-
PSA Units	-	-	-	-	4	-	-	-	-	115	-
Offsites	509	2 308	1 153	163	44	-	19 438*	-	910	80	275
Total Consumption	509	2 308	1 153	267	483	58 664	50 215	27 484	910	1 200	975
Acetylene Unit	509	2 308	1 153	-	-	-	-	-	-	-	-
Hydrogenation Unit	-	-	-	-	-	-	50 215	-	-	-	-
Mobil Process	-	-	-	-	-	-	-	-	-	-	-
PSA Unit	-	-	-	-	-	-	-	-	-	-	-
Offsites	-	-	-	30	30	-	-	27 484	910	1 200	975
Total Generation	509	2 308	1 153	30	30	58 664	50 215	27 484	910	1 200	975

* Offsite requirements are included.
** Excess LP steam (50 215 - 30 777 = 19 438 kg/h) is used for generating HP steam.

3.2 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING HYDROGEN QUENCH CONFIGURATION

The overall processing scheme is similar to that described in Section 3.1 for the electric-arc reactor using ethane quench except that the hydrogen quench system is used for acetylene production.

The operating conditions and product yields are described below.

3.2.1 Acetylene Reactor with Hydrogen Quench

The use of hydrogen for quenching the acetylene reactor effluent is particularly attractive as hydrogen acts as a suppressant for carbon formation by reducing acetylene decomposition. Also, hydrogen is formed as a byproduct with acetylene, therefore, use of hydrogen does not complicate the product separation and recovery procedure.

As shown in Figure 3-1, recycle hydrogen is mixed with natural gas and fed into the electric-arc reactors. The hot reactor effluent gas is quenched using cold hydrogen and water as in the case of acetylene reactor with ethane quench described in Section 3.1. When quenching with cold hydrogen the reactor effluent temperature is lowered to about 1200°C (instead of 900°C obtained with ethane quench). Hence, the subsequent water quenching requirements are greater than described previously in Section 3.1. The flowrates and composition of the gases leaving the reactor are as follows:

3.2 LIQUID FUELS PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING HYDROGEN QUENCH CONFIGURATION (Cont'd)

3.2.1 Acetylene Reactor with Hydrogen Quench (Cont'd)

	kg/h	mol %
C_2H_2*	67 961	12.4
C_2H_4	7 038	1.2
C_3/C_4 acetylenes C_3/C_4 dienes	1 490	0.1
C_3H_6	602	0.1
C_4H_8	119	-
C_5H_6/C_6H_6	1 041	0.1
CH_4	4 556	1.3
C_2H_6	638	0.1
C_3H_8/C_4H_{10}	906	0.1
Higher hydrocarbons	387	-
H_2	34 965	82.0
CO	3 940	0.7
N_2	5 500	0.9
HCN	6	45 ppm
H_2O	-	-
Carbon	3 098	1.0
TOTAL	132 247	100.0

The reactor SER is about 8.5 kWh/kg of acetylene formed*. On a carbon-free basis, the acetylene composition is about 12.5 mol %. The lower concentration is primarily due to some dilution of the product gas stream by quench hydrogen.

---

*acetylene formed in the arc zone = acetylene in the product stream
- acetylene in recycle feed
- acetylene formed during quenching

= 67 961 - 6577 - 0 = 61 384 kg/h

3.2 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING HYDROGEN QUENCH CONFIGURATION (Cont'd)

3.2.1 Acetylene Reactor with Hydrogen Quench (Cont'd)

At the designed capacity of 12 500 bbl/d gasoline product, the plant would require 60 acetylene reactors of 9 MW rating each. The flowrate per reactor is about 1950 kg/hr of feed or the energy requirement is 4.6 kWh/kg of feed.

The subsequent processing of reactor effluent stream and the product separation steps are the same as that described earlier in Section 3.1.

3.2.2 Overall Material and Energy Balance, Product Efficiencies and Utilities Summary

The overall material and utilities balance summary is given in Tables 3-3 and 3-4 respectively.

All the low-pressure steam required for the process is generated by recovering the process heat. Excess LP steam is used for generating HP steam.

The make-up water requirement is about 1100 m^3/h or about 4850 US gpm.

The "overall product" efficiency is 68.6 % as calculated below. Similarly, the desired gasoline product efficiency is 38.9 %.

3.2 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING HYDROGEN QUENCH CONFIGURATION (Cont'd)

3.2.2 Overall Material and Energy Balance, Product Efficiencies and Utilities Summary (Cont'd)

Input	Flowrate kg/h	HHV kJ/kg	Energy GJ/h
Natural Gas	95 291	52 515	5004
Methanol	550	22 150	46
Scrubbing Oil	1 100	42 000	12
Electricity (Net)	600 MW	3 600 kJ/kWh	2160
			7222
Output			
Gasoline	60 699	46 276	2809
Hydrogen	7 850	118 700	1389
LPG	14 664	51 400	754
			4952

Table 3-3 Overall Material and Energy Balance Summary for a 12 500 bbl/d Gasoline Plant using Electric-Arc Reactor with Hydrogen Quench

	Flowrate/Quantity	Unit Basis**** per kg of gasoline
Process Input, kg/h		
Natural Gas	95 291	1.57 kg
Scrubbing Oil	1 100	-
Methanol	550	-
Purchased Electricity, MW		
Acetylene Reactor	523 MW	8.6 kWh
Plant Use	101	1.7
*Generated Onsite	(24)	(0.4)
	600	9.9 kWh
Utilities Required		
*HP Steam (2 MPa)	70 099 kg/h	1.16 kg
**LP Steam (0.4 MPa)	36 759	-
Cooling Water (t_e=26°C, Δt=10°C)	32 849 m^3/h	0.54 m^3
Make-up Water	1100	0.018
Instrument Air (0.5 MPa, Dew Point = -25°C)	1 200 Nm^3/h	-
Nitrogen (0.4 MPa)	975	-
Products/Byproducts, kg/h		
Gasoline (12 500 bbl/d)	60 699	1.0 kg
Hydrogen	11 702	0.19
***LPG	14 664	0.24
*Residual Oil	615	0.010
*Carbon black (dry)	2 976	0.049
(wet)	1 487	0.025
*Fuel Gas (212 GJ/h)	5 104	4.15 MJ

* Residual oil, carbon black and fuel gas are used to generate steam and some electricity (24 MW) for the inplant use.

** LP steam requirement (36 759 kg/h) is met by steam produced (60 995 kg/h) in the acetylene hydrogenation unit. Excess LP steam (60 995 - 36 759 = 29 236 kg/h) is used for generating HP steam. See Table 3-4 for utilities summary.

*** LPG may be sold as a byproduct or used internally as a quench.

**** 1 kg of gasoline = 1.3706 litres.

Table 3-4 Utilities Summary for a 12 500 bbl/d Gasoline Plant using Electric-Arc Reactor with Hydrogen Quench

	Residual Oil	Carbon Black (dry)	Carbon Black (wet)	Fuel Gas	Electri-tricity	Steam HP (2HPa)	Steam LP(0.4 MPa)	Cooling Water	Make-up H_2O	Instru-ment Air	Nitrogen
Process Areas	kg/h	kg/h	kg/h	GJ/h	MW	kg/h	kg/h	m^3/h	m^3/h	Nm^3/h	Nm^3/h
Acetylene Unit	-	-	-	-	523	68 271	36 759	31 506	-	700	700
Hydrogenation Unit	-	-	-	-	3	1 828	-	1 220	-	235	-
Mobil Process	-	-	-	112	32	-	-	123	-	70	-
PSA Units	-	-	-	-	5	-	-	-	-	115	-
Offsites	615	2 976	1 487	102	61	-	24 236*	-	1 100	80	275
Total Consumption	615	2 976	1 487	212	624	70 099	60 995	32 849	1 100	1 200	975
Acetylene Unit	615	2 976	1 487	-	-	-	-	-	-	-	-
Hydrogenation Unit	-	-	-	-	-	-	60 995	-	-	-	-
Mobil Process	-	-	-	-	-	-	-	-	-	-	-
PSA Unit	-	-	-	-	-	-	-	-	-	-	-
Offsites	-	-	-	212	24	-	-	32 849	1 100	1 100	975
Total Generation	615	2 976	1 487	212	24	70 099	60 995	32 849	1 100	1 100	975

* Offsite requirements are included.
** Excess LP steam (60 995 - 36 759 = 24 236 kg/h) is used for generating HP steam.

3.3 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING LPG QUENCH CONFIGURATION

As mentioned earlier, the LPG quench process option is developed using experimental data from a "no-quench" base run (Test No. 9) and information on product yields provided by Chemische Werks Hüls. The overall plant configuration and flowrate of the major streams are as shown in Figure 3-1.

3.3.1 Acetylene Reactor with LPG Quench

The composition of the acetylene reactor effluent stream when LPG is used as a quench is as follows:

	kg/h	mol %
C_2H_2*	55 129	18.0
C_2H_4	16 957	5.1
C_3/C_4 acetylenes C_3/C_4 dienes	5 887	0.9
C_3H_6	4 326	0.9
C_4H_8	531	0.1
C_5H_6/C_6H_6	1 581	0.2
CH_4	10 759	5.7
C_2H_6	1 994	0.6
C_3H_8/C_4H_{10}	3 071	0.6
Higher hydrocarbons	2 400	0.2
H_2	15 118	63.9
CO	1 842	0.6
N_2	4 305	1.3
HCN	5	16 ppm
Carbon	3 045	1.9
TOTAL	126 950	100.0

*acetylene formed in the arc zone = acetylene in the product stream
- acetylene in recycle feed
- acetylene formed during quenching

= 55 129 - 5296 - 123 = 49 710 kg/h

3.3 LIQUID FUELS PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING LPG QUENCH CONFIGURATION (Cont'd)

3.3.1 Acetylene Reactor with LPG Quench (Cont'd)

The reactor effluent is further processed to gasoline product as described earlier in Section 3.1.

The reactor SER is about 8.5 kWh/kg of acetylene formed in the arc zone. On a carbon-free basis, the acetylene composition is about 18.3 mol%. At the designated plant capacity of 12 500 bbl gasoline/d the plant would require 50 acetylene reactors of 9 MW rating each.

3.3.2 Overall Material and Energy Balance, Product Efficiencies and Utilities Summary

A summary of overall material and utilities balances are given in Tables 3-5 and 3-6 respectively. Apart from natural gas, the plant requires substantial quantity of LPG from external sources since the LPG produced in the plant is not sufficient for quenching purposes.

The make-up water requirement is 820 m^3/h or about 3610 US gpm.

The "overall product" efficiency is 64.7% and the desired gasoline product efficiency is 46.6%, as calculated below:

Input	Flow rate kg/h	HHV kJ/kg	Energy GJ/h
Natural Gas	73 605	52 515	3 865
LPG (Net)	12 129	51 400	624
Scrubbing Oil	846	42 000	35.5
Methanol	243	22 150	5.4
Electricity (Net)	425 MW	3 600 kJ/kWh	1 530
			6 060

3.3 LIQUID FUEL PLANT WITH ELECTRIC-ARC ACETYLENE REACTOR USING LPG QUENCH CONFIGURATION (Cont'd)

3.3.2 Overall Material and Energy Balance, Product Efficiencies and Utilities Summary (Cont'd)

Output	Flow rate kg/h	HHV kJ/kg	Energy GJ/h
Gasoline	60 977	46 276	2 822
Hydrogen	9 268	118 700	1 100
			3 922

The hydrogen is produced as a byproduct.

About 86 MW of electricity is generated onsite. The balance electricity requirement of 425 MW is purchased from the utility.

Table 3-5 Overall Material and Energy Balance Summary for a 12 500 bbl/d Gasoline Product using Electric-Arc Reactor with LPG Quench

	Flowrate/Quantity	Unit Basis**** per kg of gasoline
Process Input, kg/h		
Natural Gas	73 605	1.21 kg
***LPG (Net)	12 129	0.20
Scrubbing Oil	846	-
Methanol	423	-
Purchased Electricity, MW		
Acetylene Reactor	425 MW	7.0 kWh
Plant Use	86	1.4
*Generated Onsite	(86)	(1.4)
	425	7.0
Utilities Required		
*HP Steam (2 MPa)	52 625 kg/h	0.86 kg
**LP Steam (0.4 MPa)	27 435	-
Cooling Water (t_e=26°C, Δt=10°C)	24 743 m^3/h	0.41 m^3
Make-up Water	820	0.013
Instrument Air (0.5 MPa, Dew Point = -25°C)	1 200 Nm^3/h	-
Nitrogen (0.4 MPa)	975	-
Products/Byproducts, kg/h		
Gasoline (12 500 bbl/d)	60 977 kg/h	1.0 kg
Hydrogen	9 268	0.15
*Residual Oil	2 848	0.047
*Carbon black (dry)	2 924	0.048
(wet)	1 462	0.024
*Fuel Gas (404 GJ/h)	9 944	6.63 MJ

* Residual oil, carbon black and fuel gas are used to generate steam and some electricity (86 MW) for the inplant use.

** LP steam requirement (27 435 kg/h) is met by steam produced (55 830 kg/h) in the acetylene hydrogenation unit. Excess LP steam (55 830 - 27 435 = 28 395 kg/h) is used for generating HP steam. See Table 9 for utilities summary.

*** Note: Net LPG required = LPG used as quench = LPG recycled as quench.

**** 1 kg of gasoline = 1.3706 litres.

Table 3-6 Utilities Summary for a 12 500 bbl/d Gasoline Plant using Electric-Arc Reactor with LPG Quench

	Residual Oil	Carbon Black (dry)	Carbon Black (wet)	Fuel Gas	Electricity	Steam HP (2HPa)	Steam LP(0.4 MPa)	Cooling Water	Make-up H_2O	Instrument Air	Nitrogen
Process Areas	kg/h	kg/h	kg/h	GJ/h	MW	kg/h	kg/h	m^3/h	m^3/h	Nm^3/h	Nm^3/h
Acetylene Unit	-	-	-	-	425	50 952	27 435	23 514	-	700	700
Hydrogenation Unit	-	-	-	-	3	1 673	-	1 117	-	235	-
Mobil Process	-	-	-	107	30	-	-	112	-	70	-
PSA Units	-	-	-	-	5	-	-	-	-	115	-
Offsites	2 848	2 924	1 462	297	48	-	28 395*	-	820	80	275
Total Consumption	2 848	2 924	1 462	404	511	52 625	55 830	24 743	820	1 200	975
Acetylene Unit	2 848	2 924	1 462	-	-	-	-	-	-	-	-
Hydrogenation Unit	-	-	-	-	-	-	55 830	-	-	-	-
Mobil Process	-	-	-	-	-	-	-	-	-	-	-
PSA Unit	-	-	-	-	-	-	-	-	-	-	-
Offsites	-	-	-	404	86	-	-	24 743	820	1 200	975
Total Generation	2 848	2 924	1 462	404	86	52 625	55 830	24 743	820	1 200	975

* Offsite requirements are included.

** Excess LP steam (55 830 - 27 435 = 28 395 kg/h) is used for generating HP steam.

4.0 COST ESTIMATES AND FINANCIAL ANALYSES

4.0 COST ESTIMATES AND FINANCIAL ANALYSES

Capital, operating, maintenance and product costs are presented for each of three designated commercial plants producing 12500 bbl/d of gasoline product. The estimates are developed in accordance with the techno-economic criteria outlined in Chapter 1 and based on conceptual plant design described in Chapter 3.

Financial analysis are carried out for the designated cases under two scenarios:

- in "constant" dollars assuming 100% equity financing with no escalation.

- in "current" dollars with escalation at 5% per annum assuming 40% debt financing. Interest rate on debt is taken as 12% per annum.

Profit and Loss as well as Source and Applications of Funds statements are provided. Basic financial assumptions and economic criteria are summarized in Table 4-1.

To evaluate the impact on the overall feasibility of the project, sensitivity analyses were made by varying the following key cost components:

- capital cost of the plant

- raw materials
  - natural gas
  - electricity
  - ethane or LPG quench

4.0 COST ESTIMATES AND FINANCIAL ANALYSES (Cont'd)

- revenues
  - gasoline
  - hydrogen byproduct
  - LPG byproduct

For the selected case, i.e., natural gas feed with hydrogen quench, impact of inflation and debt/equity ratio are also evaluated.

4.1 CAPITAL COST ESTIMATE

Capital cost estimates for the plant battery limits were developed on the basis of equipment cost and data received from various process developers and licensors. The offsite facilities were estimated by SNC using inhouse data. Where information was not available, factored cost estimation procedure was used.

Analysis of the costs obtained from various sources for different plant locations revealed that in many cases, the methodology and criteria used for developing the costs, differed significantly. Therefore, the estimates were adjusted for Quebec location and revised using the consistent procedure developed for the study.

About 45% of the equipment and machinery are of Canadian content. Items purchased from abroad are not available in Canada and are, therefore, exempted from custom duties. Allowance for freight has been added.

Quotations obtained in U.S. dollars were converted to Canadian dollars using an exchange rate of 1.4 (Royal Bank of Canada,

Table 4-1 Basic Financial Assumptions and Economic Criteria

Plant Capacity	:	12 500 bbl/d gasoline
Plant Location	:	Québec
Base Year of Estimate	:	January 1986
Plant Start-up Date	:	1991
Construction Period	:	3 years (1988-1990)
Plant Construction Schedule	:	
Year		%
1		22
2		48
3		30
Project and Estimating Contingency		10%
Tax Rate	:	37%
Plant Operation		
1991	:	7200 hours/year
1992-2010	:	8000 hours/year
Depreciation Method		Straight line
Plant	:	20 years
All Other Items	:	5 years
Land	:	Non depreciable
Working Capital	:	Non depreciable
Raw Material Cost		
Natural Gas	:	\$3.03/GJ (\$3.20/10^6 Btu)
Electricity	:	2¢/kWh
LPG Quench	:	18.3¢/l (\$183/m^3 or 34.2¢/kg)
Ethane Quench	:	11.1¢/l (\$110/m^3 or 29.7¢/kg)
Chemicals/Solvents/Water Cost		
Scrubbing Oil	:	18.9¢/kg (\$30/bbl)
Methanol	:	\$235/t (70.5¢US gal)
Make-up Water	:	5.3¢/m^3 (20¢/US gal)
Products/By-products Price		
Gasoline	:	35¢/l
Hydrogen	:	\$7.58 GJ (\$8/10^6 Btu)
LPG	:	18.3¢/l (\$183/m^3 or 34.2¢/kg)
Financial Analysis		
Constant Dollars	:	assuming 100% equity with no escalation
Current Dollars	:	40% financing at 12% interest rate and escalation at 5% per annum.

4.1 CAPITAL COST ESTIMATE (Cont'd)

Foreign Exchange Quotation, December 85/January 86). Simularly, a currency factor of 0.5960 was used for the West German Deutsche Mark.

Machinery and equipment costs obtained from U.S.A. were adjusted for inflation to the base year of estimate (January 1986) using Marshall and Stevens Equipment Cost Index. For converting U.S. cost data for a complete process unit, Chemical Engineering Plant Index was applied. For updating costs obtained from Canadian sources, Chemical and Petroleum Plant Index published by Statistics Canada was used.

Most of the bulk materials such as piping, cables, fittings and concrete, are assumed to be purchased in Canada. In some cases, the quotations were expresed in U.S. dollars (Gulf Coast) which were adjusted to Quebec location using the bulk-material price differential factor of 1.26 as calculated in Appendix D-1.

Estimates of construction-labor manhours supplied by the process developers for U.S. Gulf Coast locations were revised using a productivity adjustment factor of 1.10 (see Appendix D-2). To convert from West German conditions, an adjustment factor of 1.14 was applied [Chauvel et al, Manual of Economic Analysis of Chemical Processes, 1976].

A typical winterizeration factor of 2% was added to the plant cost to account for the climatic conditions in Québec, which necessitate deeper foundation, extra insulation, heat tracing of pipes, etc.

4.1 CAPITAL COST ESTIMATE (Cont'd)

Table 4-2 provides the breakdown of capital cost estimates by process areas. The total installed plant cost (TIPC) includes all the equipment for onsite and offsites, bulk materials, construction labor, engineering and project management and other indirect construction costs. A contingency of 10% has been added.

Based on discussions with Federal and Provincial agencies (Regional Industrial Expansion, Government of Canada; Ministère de l'industrie et du Commerce, Gouvernemnt du Québec), it was assumed that a project of this nature would attract a 15% grant towards the capital cost of the plant. Also subsidies available from Hydro-Québec under "Le programme d'aide à implantation des électro-technologies" was considered.

Prepaid license fees are estimated based on communication with the process developers [Müller 1983, Weiss 1984, Mori 1984].

Cost of "initial charge" of catalysts and chemicals required for the process have been capitalized. This cost was estimated based on 30-day requirement of chemicals for the normal plant operation.

Other start-up and miscellaneous expenses during commissioning period are taken as 3% of TIPC for any minor modifications and changes that may be required.

Working capital has been estimated for 30-day operating supplies, chemicals and other consumables (except water), spare parts, warehouse stock, payroll burden, overhead expenses, and a 7-day inventory cost of gasoline product.

4.1 CAPITAL COST ESTIMATE (Cont'd)

Land costs are calculated for a 100-acre site (about 400 000 m^2) at an average rate of \$3/m^2.

Interest during construction is not shown in Table 4-2 which is expressed in "constant" dollars for 100% equity financing scenario. However, for "current" dollar analysis, the interest is capitalized for the three year construction period based on the capital disbursement schedule outlined in Table 4-1. Details are provided in Appendix E under "Sources and Applications of Funds" for the three cases.

Total investment costs shown in Table 4-2 does not include:

- allowance for process development cost and possible changes in design due to advancement of technology after commencement of construction.
- natural gas pipeline and distribution system outside the battery limits.
- electricity generation and distribution network outside the plant site.
- hydrogen product distribution pipeline.
- water supply and pipelines to the site.

Table 4-2 Capital Cost Estimates and Total Investment for a 12 500 bbl/d Gasoline Plant, in millions of Canadian Dollars (January 1986)

	Ethane Quench	Hydrogen Quench	LPG Quench
Acetylene Production, Carbon Black Recovery and Higher Acetylene Separation	169.64	192.80	186.50
Acetylene Hydrogenation Unit	29.64	34.00	31.93
Mobil MOGD Process	70.54	76.26	74.60
PSA Unit for H_2 Recovery	24.93	51.73	24.50
Total Onsite Cost	294.75	354.79	317.53
Steam Generation	4.06	4.68	3.70
Incineration	1.95	1.87	2.03
Water Treatment	1.07	1.20	1.0
Electrical Equipment	80.33	97.34	83.80
Steam Cooling and Process H_2O	17.63	19.62	17.53
Refrigeration	8.33	9.43	7.74
Site Preparation, Bldgs, etc.	23.42	23.42	23.42
Sewer, Fire Protection, Fence & Flare	5.0	5.0	5.0
Air Supply	1.74	1.74	1.74
Product Shipping and Storage	11.00	11.86	10.81
Inter Connecting Pipe Racks	6.36	7.34	6.53
Total Plant Cost	455.64	538.29	480.83
Contingency	45.56	53.81	48.07
Total Installed Plant Cost (TIPC)	501.20	592.10	528.90
Subsidies/Grants			
Capital Cost Grant	(75.18)	(88.81)	(79.33)
Hydro-Québec Grant	(39.16)	(37.44)	(40.38)
Total Plant Cost, Net of Grants	386.86	465.85	409.19
Indirect Capital Investment			
License and Prepaid Royalties	1.79	1.79	1.79
Initial Catalyst and Chemicals	1.40	2.26	1.74
Start-up and Other Costs	15.04	17.76	15.87
Working Capital*	15.04	17.76	15.87
Land*	1.20	1.20	1.20
Total Capital Investment	421.33	506.62	445.66

* non-depreciable items

4.1 CAPITAL COST ESTIMATE (Cont'd)

- housing, community facilities and associate infrastructure.
- roads and transportation facilities.

4.2 ANNUAL OPERATING, MAINTENANCE AND PRODUCTION COSTS

Annual operating, maintenance and production costs expressed in "constant" dollars (January 1986) are presented in Table 4-3 for a normal plant operation of 8 000 hours per year.

Raw materials, utilities, catalysts and chemical costs have been calculated using the unit cost data given in Table 4-1 and the estimated requirement presented earlier in Tables 3-1, 3-3 and 3-5 respectively.

Royalties are estimated at DM 12/tonne of acetylene (or about 0.7 ¢/kg of C_2H_2) produced [Müller 1983]. These royalties are considered for 10 years of production, i.e., from 1991-2000, and none thereafter. For proprietary reasons, running royalties for the Mobil MOGD process is included by the process developer in the annual cost of catalyst consumed.

Operating and supervisory labour cost (excluding maintenance labour) are calculated for 3 shifts per day using the manpower requirement specified by the respective process developers. For annual disbursement, average hourly rates were multiplied using a factor of 1940 hours per year:

Table 4-3 Annual Operating, Maintenance and Production Costs, in millions of Canadian Dollars (January 1986)

Plant Capacity: 12 500 bbl/d gasoline product
Plant Operation: 8 000 hours/year

	Ethane Quench	Hydrogen Quench*	LPG Quench
Natural Gas	71.84	121.30	93.70
Electricity	72.48	96.00	68.00
Quench (Ethane)	85.35	-	-
(LPG)	-	-	33.18
Catalyst and Chemicals**	16.16	18.46	17.22
Make-up Water	0.38	0.46	0.35
Royalties (10 years)	2.40	3.89	3.15
Labour, Supervision and Operating Supplies	2.61	2.61	2.61
Maintenance (incl. labour)	15.04	17.76	15.87
Property Taxes and Insurance	7.52	8.88	7.93
Overhead and Administration	6.18	7.13	6.47
Total Production Cost (excl. depreciation)	279.96	276.49	248.48

* hydrogen generated in the plant is recycled to the arc reactors as quench.

** for proprietory reasons, MOGD royalties is included by the process developer in the annual cost of catalyst consumed.

4.2 ANNUAL OPERATING, MAINTENANCE AND PRODUCTION COSTS

	Manpower Required	Hourly Rate
• Operating labour		
- Onsite	26	
- Offsite	11	
	37	$16.00
• Supervisory labour		
- Onsite	9	
- Offsite	5	
	14	$18.00

A labour burden of 35% has been added to the direct labour cost to cover for fringe benefits.

Operating supplies are estimated at 35% of the direct labour cost.

The annual maintenance cost was taken as 3% of the total installed plant cost (TIPC). This includes maintenance materials and supplies, equipment replacement cost, labour, supervision, labour burden, and other regular contract maintenance cost.

Property taxes and insurance are assessed at 1.5% of TIPC.

Plant overhead and administration is assumed to be 35% of direct labour cost, labour burden and maintenance cost. It includes plant management, engineering and technical staff, medical services, personnel, accounting, clerical, sales and marketing staff.

4.2 ANNUAL OPERATING, MAINTENANCE AND PRODUCTION COSTS (Cont'd)

The total annual production cost, excluding depreciation, may be summarized as follows:

	Ethane Quench	Hydrogen Quench	LPG Quench
Total Production Cost, $ million	279.26	276.49	248.48
By Product Credits, $ million:			
- Hydrogen	(68.41)	(84.27)	(66.75)
- LPG	(35.34)	(40.12)	-
Net Production Cost, $ million	176.21	152.10	181.73
Gasoline Production Cost, ¢/l (excluding depreciation)	26.5	22.9	27.4

If by product credits are taken, the unit production cost of gasoline (excluding depreciation) is about 23¢/l when hydrogen is used as a quench and 27.4¢/l for the LPG quench case.

4.3 FINANCIAL ANALYSIS

To account for depreciation, capital recovery cost and taxes over the life of the project, financial analysis were carried out for each of the three cases under two scenarios:

- in constant dollars assuming 100% equity financing with no escalation
- in current dollars assuming 40% debt financing with escalation at 5% per annum. Interest rate on debt is taken as 12% per annum.

4.3 FINANCIAL ANALYSIS (Cont'd)

4.3.1 Project Life and Terminal Worth

THe life of the project is considered to be 23 years; 3 years of construction and 20 years of operation. For the analysis, the first year of construction is assumed to be 1988. At the end of the project in the year 2010, the cost of land and working capital are fully recovered. For other capital components, a zero salvage value is assumed.

4.3.2 Plant Operation

The plant is assumed to operate at 7 200 hours in the first year and 8 000 hours in the subsequent years.

4.3.3 Capital Cost Allowance

Capital cost allowance (depreciation) is calculated on a straight-line basis according to the following schedule:

- Land and Working Capital 0%
- Plant Cost 5%
- Initial Catalysts and Chemicals 20%
- Start-up Expenses 20%
- Prepaid License Fees 20%

4.3.4 Taxable Income and Taxes

Operating losses, if any, are carried forward up to five years to calculate taxable income. Federal and Provincial income taxes are taken as 37% of the taxable income.

4.3 FINANCIAL ANALYSIS (Cont'd)

4.3.5 Long-Term Financing

For the "current" dollar analysis, 40% of the capital cost of the plant (TIPC) is assumed to be financed through a long-term debt. Interest expenses are capitalized during the first three years (construction period) and the loan is repaid in ten equal annual instalments commencing from the first year of operation. The loan bears an interest of 12% per annum.

4.3.6 Escalation Rate

An average inflation fator of 5% per annum over the life of the project is assumed. While this value is not to be intepreted as a forecast, it creates a scenario which corresponds to the current general conditions and allows comparison of internal rates of return with alternate earning opportunities.

4.3.7 Results

For each case, a Profit and Loss as well as Sources and Applications of Funds Statement are provided in Appendix E for both constant and current dollar analyses. The key results are summarized in Table 4-4.

The financial analysis in constant dollars with 100% equity financing indicates that an internal rate of return on equity (ROE)* ranges from 8.3-12.6% before taxes in "real" terms and 6.1-9.0% after taxes. For a project of this nature, this may be considered as an acceptable rate of return based on gasoline transfer price of 35¢/l at the plant gate.

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* in constant dollar analysis, return on equity is expressed in "real" terms, i.e., current rates minus inflation.

Table 4-4 Financial Analysis Results

	Ethane Quench	Hydrogen Quench	LPG Quench
Constant Dollar Analysis *			
ROE (before taxes),%	10.2	12.6	8.3
(after taxes), %	7.4	9.0	6.1
Payback Period, years			
(before taxes), %	7.7	6.5	9.0
(after taxes),%	10.0	8.6	11.3
Current Dollar Analysis			
ROE (before taxes),%	16.7	20.2	14.1
(after taxes),%	12.9	15.5	10.9
Payback Period, years			
(before taxes)	7.2	5.5	9.1
(after taxes)	9.6	7.4	11.0
Average Return on Sales, %	7.0	10.3	6.5
Average Return on Fixed Assets, %	10.5	13.7	8.7
Debt Coverage Ratio			
Minimum	1.5	1.7	1.4
Year	1992	1992	1992
Maximum	1.8	2.1	1.6
Year	2000	2000	2000

* in constant dollar analysis, return on equity is expressed in real terms, i.e., current rate minus inflation.

4.3 FINANCIAL ANALYSIS (Cont'd)

4.3.7 Results (Cont'd)

In the current dollar analysis with 40% debt financing, the ROE varied from 14.1-20.2% before taxes and 10.9-15.5% after taxes, being the highest for the hydrogen quench case. The payback period is 5.5 years. Debt coverage range is greater than 1.5, considered a typical minimum by the lending institutions. Return sales and fixed assets are about 10% and 14% respectively.

4.3.8 Sensitivity Analyses

To evaluate the impact of cost variations on the project feasibility, sensitivity analysis were performed on the key variables in the following range:

	Base Case	Range
. Capital Cost of the Plant	As estimated	-20% to +20%
. Raw Materials		
- Natural Gas	$3.03/GJ	-10% to +30%
- Electricity	2.0¢/kWh	-10% to +30%
- Ethane Quench	11.14¢/l	-10% to +30%
- LPG Quench	18.34¢/l	-10% to +30%
. Products/Byproducts		
- LPG	18.3 ¢/l	-10% to +30%
- Hydrogen	$7.55/GJ	-30% to +10%
- Gasoline	35¢/l	-10% to +30%

4.3 FINANCIAL ANALYSIS (Cont'd)

4.3.8 Sensitivity Analyses (Cont'd)

A complete set of results for each of the three designated plant configurations is attached in Appendix F. Figures 4-1 to 4-3 show the graphical variations of the return on equity (before taxes), expressed in current terms, for the three cases respectively. The dotted curves represent extrapolation beyond the specified ranges.

In general, the project is typically most sensitive to revenues, particularly the gasoline transfer price, moderately sensitive to the plant capital cost and least sensitive to the cost of individual raw materials.

For example, as seen in Figure 4-2 for the hydrogen quench case, a 10% increase in the gasoline price (i.e., to 38.5¢/l) would increase the ROE by 5.5% to 25.7% before taxes. Similarly, a 10% increase in the total plant cost reduces the ROE by 2.7% to 17.5%. A combination of these two events, would yield 23% before taxes. Thus, these curves may be used for single as well as multivariable study to determine under which conditions the proposed project would be feasible or not.

Impact of cost variations on other key financial parameters such as payback period, terminal worth of the project, return on sales or fixed assets, and debt coverage ratio is tabulated in Appendix F. For example, for the hydrogen quench case, a 10% increase in gasoline transfer price improves the payback period from 5.5 years to 3.9 years, debt coverage ratio from 1.7 to 2.1 and return on sales from 10.3% to 14.7%.

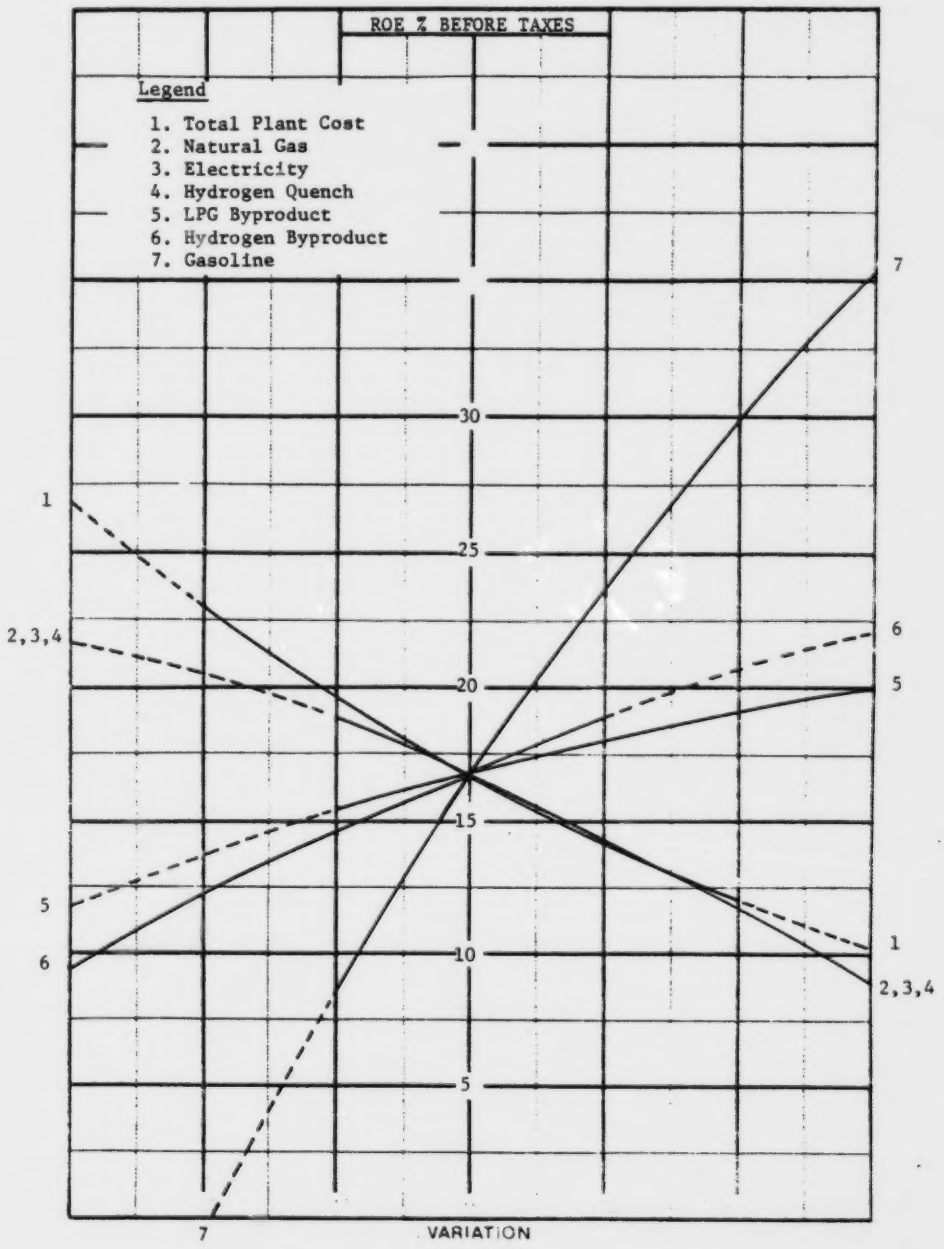

Figure 4-1 Sensitivity Analyses for the Ethane Quench Case (in Current Dollars assuming 40% Debt Financing)

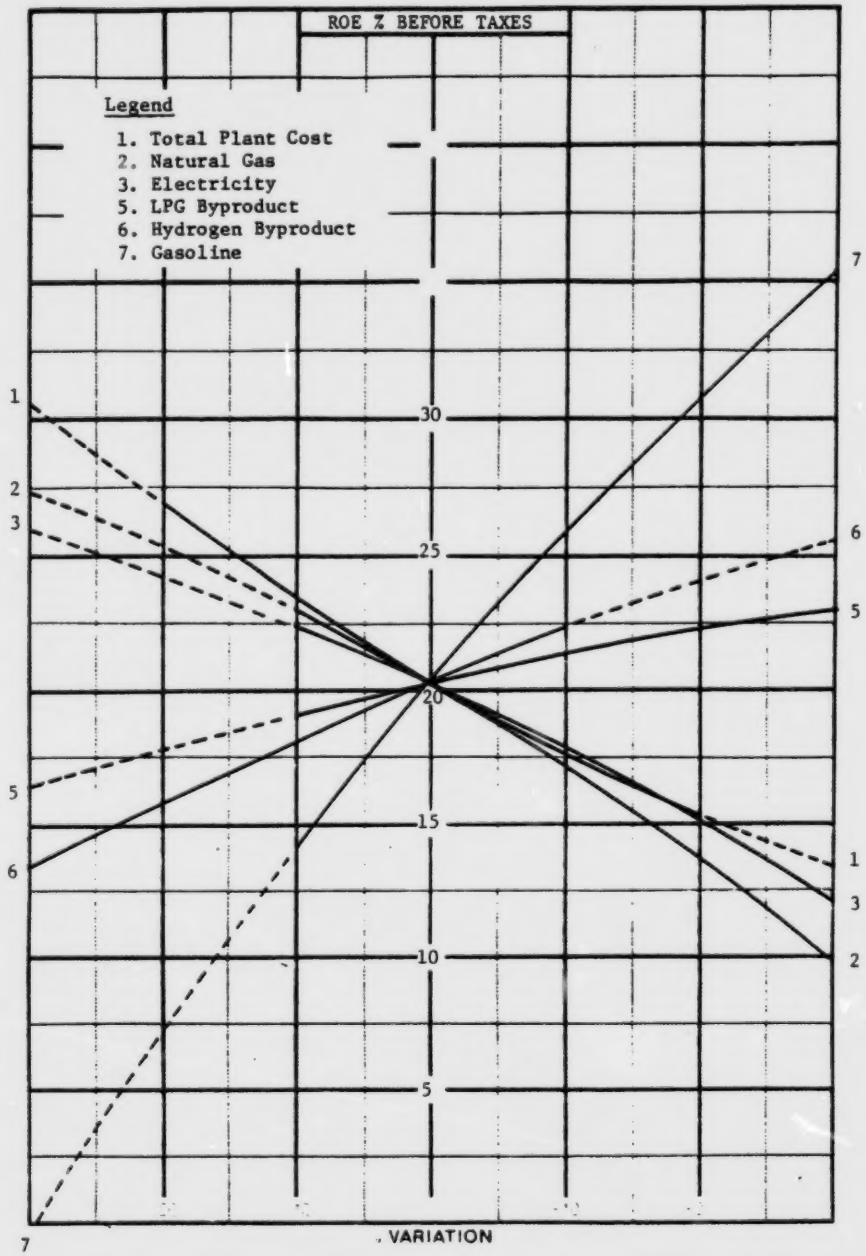

Figure 4-2 Sensitivity Analyses for the Hydrogen Quench Case (in Current Dollars assuming 40% Debt Financing)

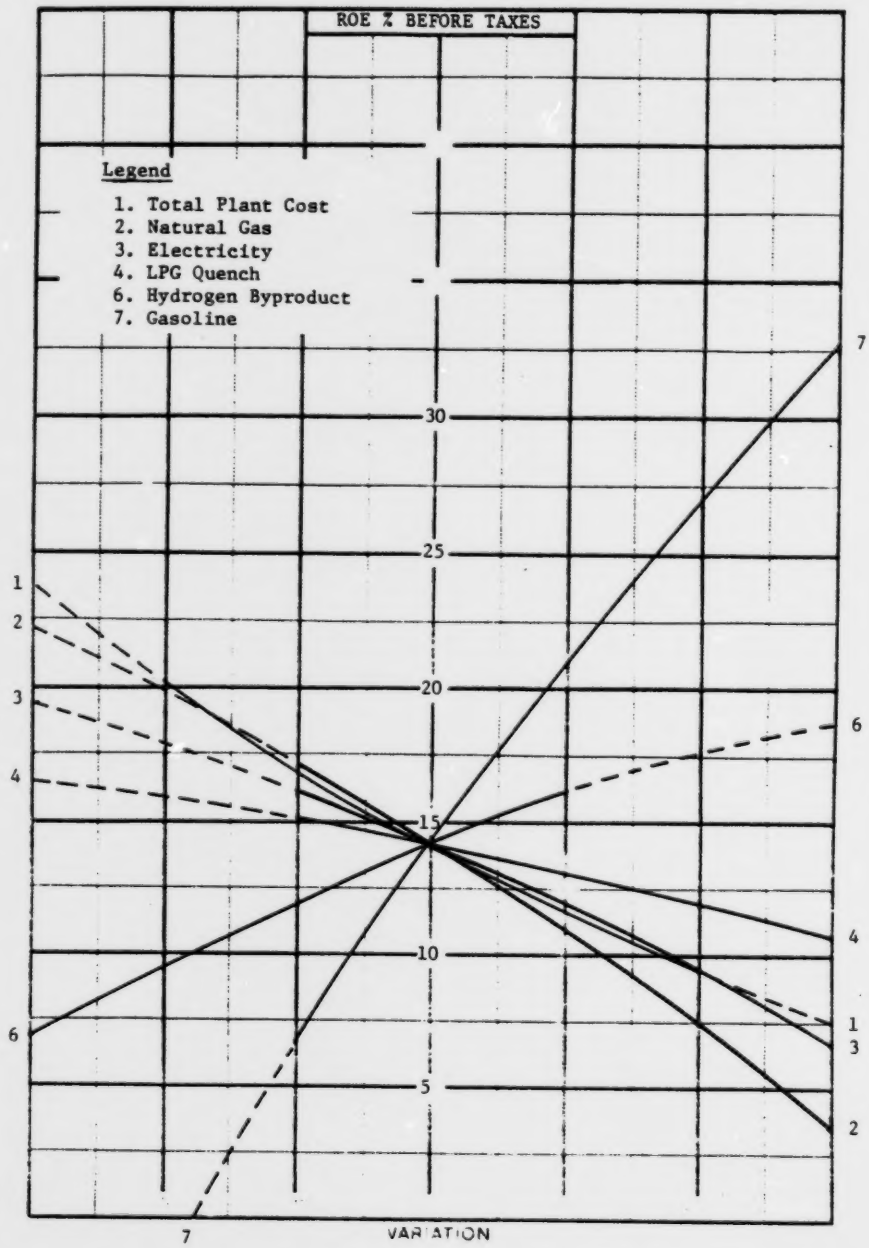

Figure 4-3 Sensitivity Analyses for the LPG Quench Case (in Current Dollars assuming 40% Debt Financing)

4.3 FINANCIAL ANALYSIS (Cont'd)

4.3.8 Sensitivity Analyses (Cont'd)

An evaluation of financial results indicate that a liquid fuel plant with hydrogen quench configuration appears to be most promising. For the selected hydrogen quench case, two additional sensitivity analyses were made to evaluate the impact of inflation rate and debt/equity ratio on the feasibility of the project. The results are attached in Appendix G.

Discussions with Natural Gas Branch of Energy Mines and Resources, Gaz Métropolitain, Hydro-Québec and National Energy Board suggested that the "real" prices of energy related items are expected to decline at least in the near future. The Energy Branch is predicting 2-3% increase as opposed to 4-5% general inflation rate. Therefore, for the financial analysis, prices of gasoline, hydrogen, LPG or ethane, natural gas and electricity were escalated at the rate of 3% per annum while for all other operating cost components, a general inflation factor of 5% per year was applied. The return on equity dropped to a marginal value of 13.5% before taxes. However, it should be noted that a 2% differential in unlikely to be sustained on a long-term basis, i.e., over the entire 20 years life of the project.

With higher debt/equity ratio, i.e., 60% financing, the ROE increased marginally to 21.6% before taxes and 16.8% after taxes. The average debt coverage ratio is 1.4. Payback period is about 6 years.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.0 CONCLUSIONS AND RECOMMENDATIONS

The proposed route for liquid fuel (gasoline) production from natural gas via an electricity-based acetylene process offers an attractive synfuel approach, particularly for locations where cheap electricity and natural gas are available. For Canada, this route has two main advantages:

- combined use of both surplus natural gas and electricity to produce valuable end-products.

- decrease Canada's dependence on imported oil, particularly for Eastern Canada region, by shifting to utilization of huge shut-in reserves in the country.

From the results of the experimental program and the techno-economic evaluation, the following observations and conclusions are made:

- Thermodynamics of acetylene formation show that free energy of acetylene decreases at higher temperatures ($>$ 1200°C) in contrast to the behaviour of other hydrocarbons, therefore, acetylene is a predominant specie formed.

- Rapid heating followed by rapid quenching is essential for desired conversion and acetylene yield. The residence time in the electric-arc reactor is in the order of milliseconds ($<$ 5 ms).

- Direct quenching with a suitable quenchant is not only an efficient method of stabilizing the acetylene product but also serves to recover part of the process heat, hence, improve the overall thermal efficiency of the process.

5.0 CONCLUSIONS AND RECOMMENDATIONS (Cont'd)

- The results of the experimental program show that methane (natural gas) feed alone is more suitable. Addition of hydrogen to natural gas feed resulted in higher specific energy requirement (SER) and lower product yields (Y) and concentrations (C).

  - The optimum natural gas feed was determined to be 8.3 l/s (18.7 scfm).

  - The use of methane as a quench resulted in higher SER and lower Y and C values compared to hydrogen and ethane quench runs.

  - With hydrogen as a quench, the main product is acetylene; negligible ethylene is formed. The optimum hydrogen quench rate is 6.7 l/s (15 scfm). At this value, the SER is minimum, about 8.6 kWh/kg of acetylene formed.

  - With ethane as a quench, a substantial quantity of ethylene is also formed as a byproduct (upto 0.28 kg/kg of acetylene). Ethane not only acts as a quench but takes part in the reaction. The optimum ethane quench flowrate was determined to be 2.2 l/s (5 scfm).

  - The location of the quench injection point relative to the arc is an important parameter in the design of the reactor, particularly when using a hydrocarbon quench.

  - For ethane quench, runs made at reduced primary quench distance of 7.5 cm show that while there was no significant improvement in acetylene yield (Y_1) and SER_1 value, the overall product yield (Y_2) is about 10% higher and SER_2 almost 10% lower.

5.0 CONCLUSIONS AND RECOMMENDATIONS (Cont'd)

- The operation of the designated electric-arc is sensitive to process variations, however, stability of the arc can be maintained by either "rotating" the feed gas stream through a tangential feed chamber or by rotating the arc itself by a surrounding magnetic field. There is no inherent advantage of one method over the other, although recent developments favor the latter approach.

- In spite of non-uniform temperature profile in the arc zone, there is no operational difficulty associated with maintaining the desired "average" conversion and composition of the "total" product gas stream.

- The reactor specific energy requirement based on acetylene yield is in the range of 8.5 - 10.7 kWh/kg of acetylene; being the lowest for the hydrogen quench case. The SER_2 value is between 5.8 - 7.6 kWh/kg of acetylene and ethylene formed; being highest for the hydrogen quench. However, the overall process SER is in the range of 7 - 8.6 kWh/kg of gasoline formed.

- The overall thermal efficiency of the liquid fuel plant via acetylene is 65 - 72%, being the highest for the ethane quench case. The desired liquid product efficiency is between 39 - 47%, being highest for the LPG quench case.

- The total capital investment for a 12 500 bbl/d gasoline plant ranges from about $420 - 505 million dollars. The proposed route is less capital intensive compared to other synfuel technologies. The capital investment of $ 40 000/daily barrel of gasoline product is 30% lower compared to Fischer Tropsch or Mobil MTG process.

5.0 CONCLUSIONS AND RECOMMENDATIONS (Cont'd)

- The unit production cost of gasoline (excluding depreciation) is about 23¢/l when hydrogen is used as a quench and 27.4¢/l for the LPG quench case.

- The financial analysis in "constant" dollars with 100% equity financing for the liquid fuel plant yields an internal rate of return on equity (ROE) from 8.3 - 12.6% before taxes in "real" terms and 6.1 - 9% after taxes. For a project of this nature, this may be considered as an acceptable rate of return based on gasoline transfer price of 35¢/l at the plant gate.

- The result of "current" dollar analysis with 40% financing show that ROE ranges from 14.1 - 20.2% before taxes and 10.9 - 20.2% before taxes and 10.9 - 15.5% after taxes, being the highest for the hydrogen quench case. The payback period is 5.5 years. Debt coverage ratio is greater than 1.5, considered as a minimum by most lending institutions.

- Typically, the project is most sensitive to revenues, particularly the gasoline price, moderately sensitive to plant capital cost and less sensitive to the cost of raw materials.

- For the selected hydrogen quench case, a 10% increase in the transfer price of gasoline (i.e, to 38.5¢/l) increases the ROE by 5.5% to 25.7% before taxes. Similarly, a 10% increase in the total plant cost reduces the ROE by 2.7% to 17.5%. A combination of these two events, would yield 23% before taxes. Alternatively, at a marginal ROE of 15%, the required gasoline transfer price is only 32¢/l.

5.0 CONCLUSIONS AND RECOMMENDATIONS (Cont'd)

- Amongst the process configurations investigated, the hydrogen quench yields the highest ROE (> 20%) and appears to be most attractive for the production of gasoline from natural gas via acetylene.

- All the technologies considered in the conceptual, commercial plant design are commercially available today, except for the hydrogen quench system and the Mobil MOGD process.

- The commercial scale-up of hydrogen quench system is not considered as critical, since similar reactor configuration with LPG quench has been in commercial operation at Chemische Werke Hüls in Germany for over 40 years. The MOGD process has been demonstrated on a pilot scale by Mobil Oil Corporation. In this case as well, a similar Mobil-MTG process with identical catalyst and reactor configuration but operating under different conditions has been commercialized now in New Zealand.

- The novel proposed scheme for liquid fuel production via acetylene appears to be attractive for locations where cheap electricity (< 2¢/kWh) and natural gas (< $3.00/GJ) are available.

- The proposed route would yield other spinoff benefits, since cheap acetylene may be recovered to produce other acetylene-derived chemicals.

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APPENDIX A

THERMODYNAMICS AND KINETICS CONSIDERATION FOR ACETYLENE PRODUCTION

In general, the method of producing acetylene by thermal pyrolysis of hydrocarbons takes advantage of the fact that the free energy of acetylene decreases at higher temperatures in contrast to the behavior of other hydrocarbons. Figure A-1 is a plot of free energy of formation of various hydrocarbons including acetylene (C_2H_2) as a function of temperature.

At 1500° K or higher, acetylene has lower free energy (more stable) than any other hydrocarbon, therefore acetylene becomes a predominant specie at higher temperatures. But even at these high temperatures, acetylene is less stable than its free elements (carbon and hydrogen). The curves in Figure A-1 also indicate that the temperature for the formation of acetylene decreases with an increase in the molecular weight of the paraffinic hydrocarbons.

The amount of energy required to convert the hydrocarbons is very large and must be applied at high temperatures to achieve a favorable free energy relation. A calculation of the theoretical energy requirement has been reported [Miller 1966] based on the following general equation and a reaction temperature at which Kp for the reaction was 100:

$$\frac{2}{n} C_n H_{2n+2} \rightleftharpoons C_2H_2 + (1 + \frac{2}{n} H_2)$$

Hydrocarbons	Reaction Temp,°C	Heat of Reaction at 25 C, kJ/mol*	Sensible Heat kJ/mol*	Heat Required per Unit of C_2H_2	
				kJ/mol*	kWh/kg
Methane	1470	376.6	227.6	604.2	6.45
Ethane	1160	311.3	144.3	455.6	4.86
Propane	1090	295.8	123.8	419.6	4.48
Butane	1000	289.1	114.2	403.3	4.31

* mol = gram mole

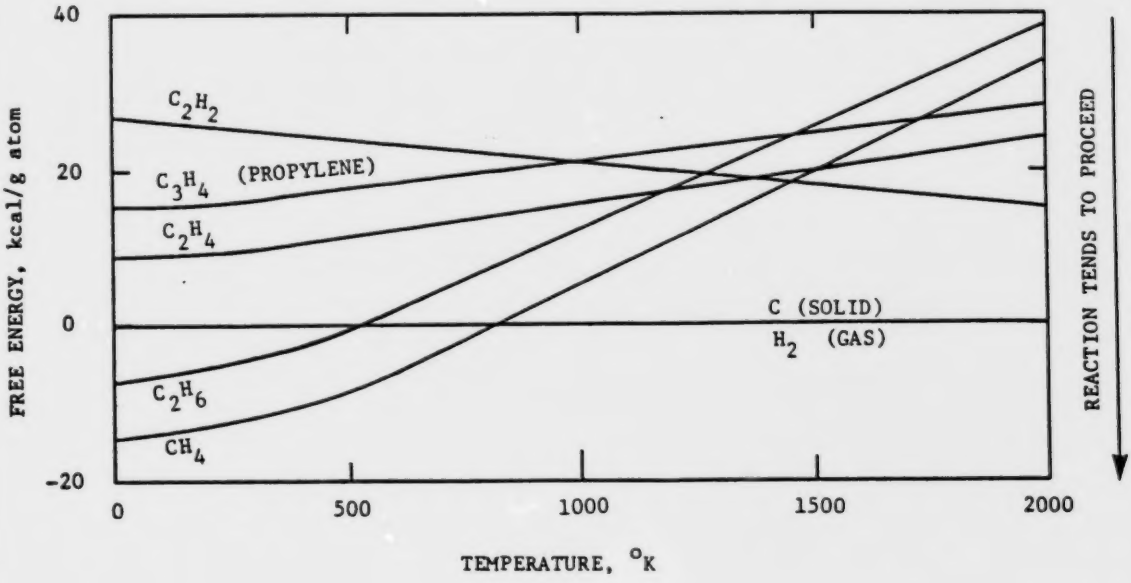
In addition, to the tabulated theoretical heat requirement, energy must also be supplied for:

- heat losses (in water-cooled electrodes, radiation to the reactor chamber walls)
- enthalpy of unreacted feedstock
- heat supplied to inert elements present in feedstock, e.g. N_2
- energy requirement for the side reaction, such as formation of olefins (e.g. ethylene) or of carbon (e.g. thermal decomposition of C_2H_2 $\quad 2C + H_2$ is exothermic), and
- energy requirement for plant operation

The thermodynamic data show that with an increasing chain length, the energy requirements are less to convert hydrocarbons to acetylene. Also, typical data for heat of formation of various hydrocarbons divided by the number of carbon atoms in the hydrocarbon support the above results as shown below:

	kJ/carbon atom at 1500° C
methane	-92.4
ethane	-53.9
n-octane	-31.9
carbon	0
ethylene	+18.1
acetylene	+110.1

The decomposition of hydrocarbons (mainly acetylene) to carbon and hydrogen begins at a relatively low temperature. In the case of methane, for example, this occurs at about 600° C [Kirk and Othmer 1964]. Hence, the decomposition proceeds in competition with the formation of acetylene. However, the rate of acetylene formation is greater than that of the decomposition reaction



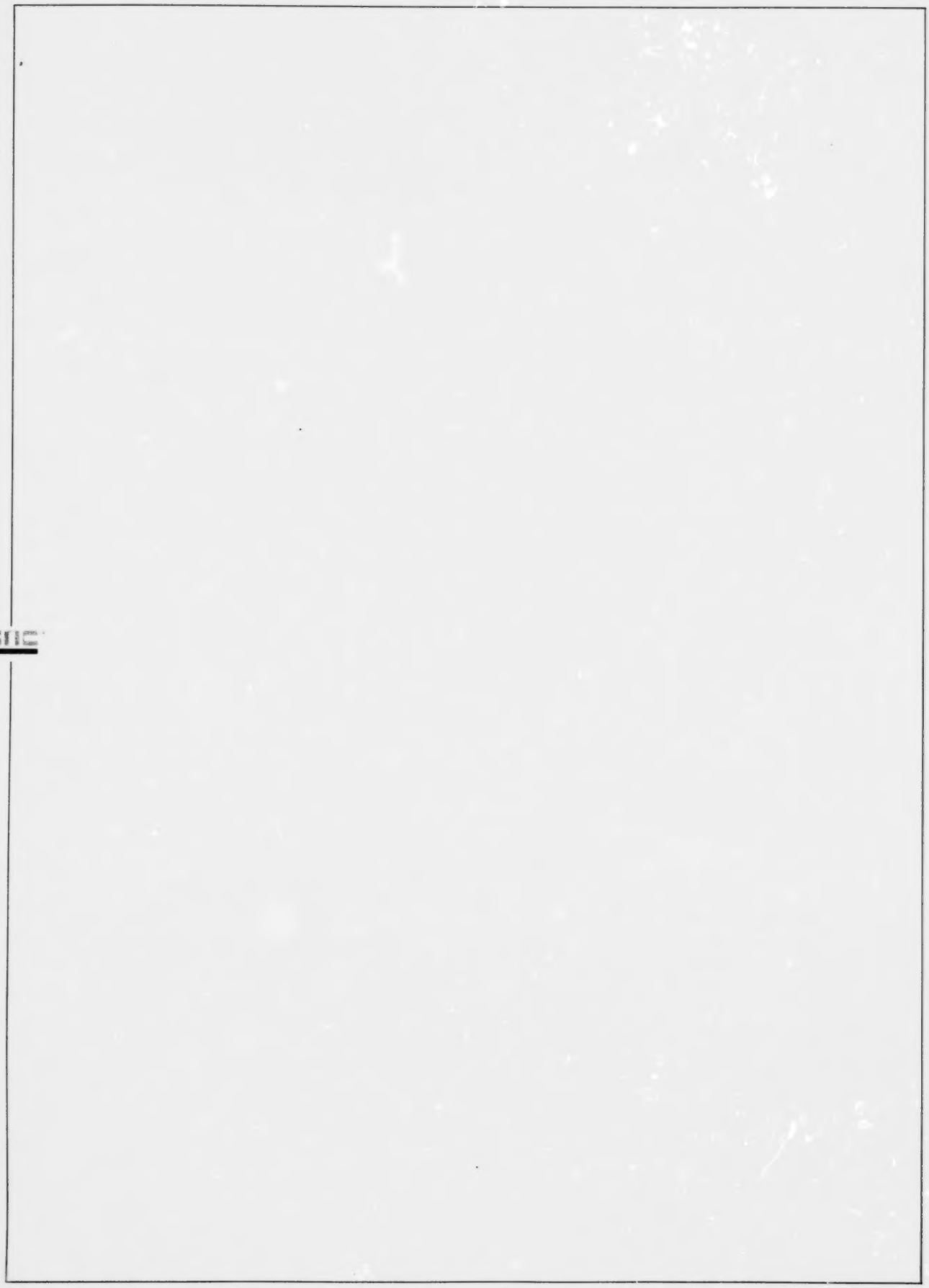
Note: 1 kcal = 4.184 kJ

Figure 1: Free Energy of Formation of Some Hydrocarbons

[Leroux 1961, Palmer 1964]. Therefore, the commercial manufacture of acetylene from pyrolysis of hydrocarbon must involve rapid heating of the feedstock, followed by rapid quenching of the product to minimize the decomposition of acetylene formed.

APPENDIX B

ARC-ACETYLENE FROM NATURAL GAS
(EXPLORATORY EXPERIMENTS)
AVCO EVERETT RESEARCH LABORATORY, INC.
Final Technical Report
May 1985



ARC-ACETYLENE FROM NATURAL GAS

(EXPLORATORY EXPERIMENTS)

Final Technical Report
Subcontract OSQ84-00209

August 1985

prepared for

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ABSTRACT

Exploratory testing was carried out on conversion of methane to acetylene in an arc reactor. Avco's 100-kW facility was used. The results are highly favorable to process feasibility. We demonstrated SER values of less than 4kW-hr/lb of C_2H_2, using H_2 and C_2H_6 quenches. Even better performance can be projected for scaled - up reactors (> 1 MW).

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1.0 INTRODUCTION

The central objective of the effort under Avco's subcontract was to obtain data to support a techno-economic assessment by SNC of the feasibility of producing distillate fuels from natural gas through an electricity-based acetylene process. The approach was to perform limited testing (33 data points) using Avco's 100-kW arc facility, with the recognition that this effort was exploratory and that definitive answers to the detailed technical questions would require an effort of greater scope.

The thermodynamic foundation of the process is illustrated in Figure 1-1. At high temperatures, the favored hydrocarbon is C_2H_2. To generate the high enthalpies associated with the desired conditions, CH_4 is passed through an electric arc, which deposits the required power in the gas. After partial equilibrium has been reached at high temperature (approximately a few milliseconds before soot formation begins), the hot gas is rapidly quenched by the addition of another flow of cold gas. If this latter process is performed quickly enough, the composition will be "frozen" at near the high temperature values. The theoretical minimum SERs are less than 3.

The results are highly favorable to process feasibility. With CH_4 feed and H_2 quench, we found SER (specific energy requirement) values of < 4 kW-hr/lb C_2H_2, with yield greater than 80 percent (on a carbon-conversion basis) and C_2H_2 concentration greater than 10 percent at our maximum operating pressure of 330 mm Hg. With CH_4 feed and C_2H_6 quench, we observed high yields of C_2H_4 as well as C_2H_2, with SER values less than 4, based on C_2H_2 alone, and less than 3, based on lbs C_2H_2 + lbs C_2H_4; a yield of 65 percent (carbon in C_2H_2 and C_2H_4/carbon in CH_4 and C_2H_6); and concentrations of 15 percent for C_2H_2 and more than 20 percent for C_2H_2 and C_2H_4 in the product gas; all at 330 mm Hg. Even better performance can be projected for scaled-up reactors (> 1 MW).

For commercial reactors larger than 1 MW, with hydrogen quench we predict (based on acetylene yield) at 0.5 - 1 atm operating pressure, SER of

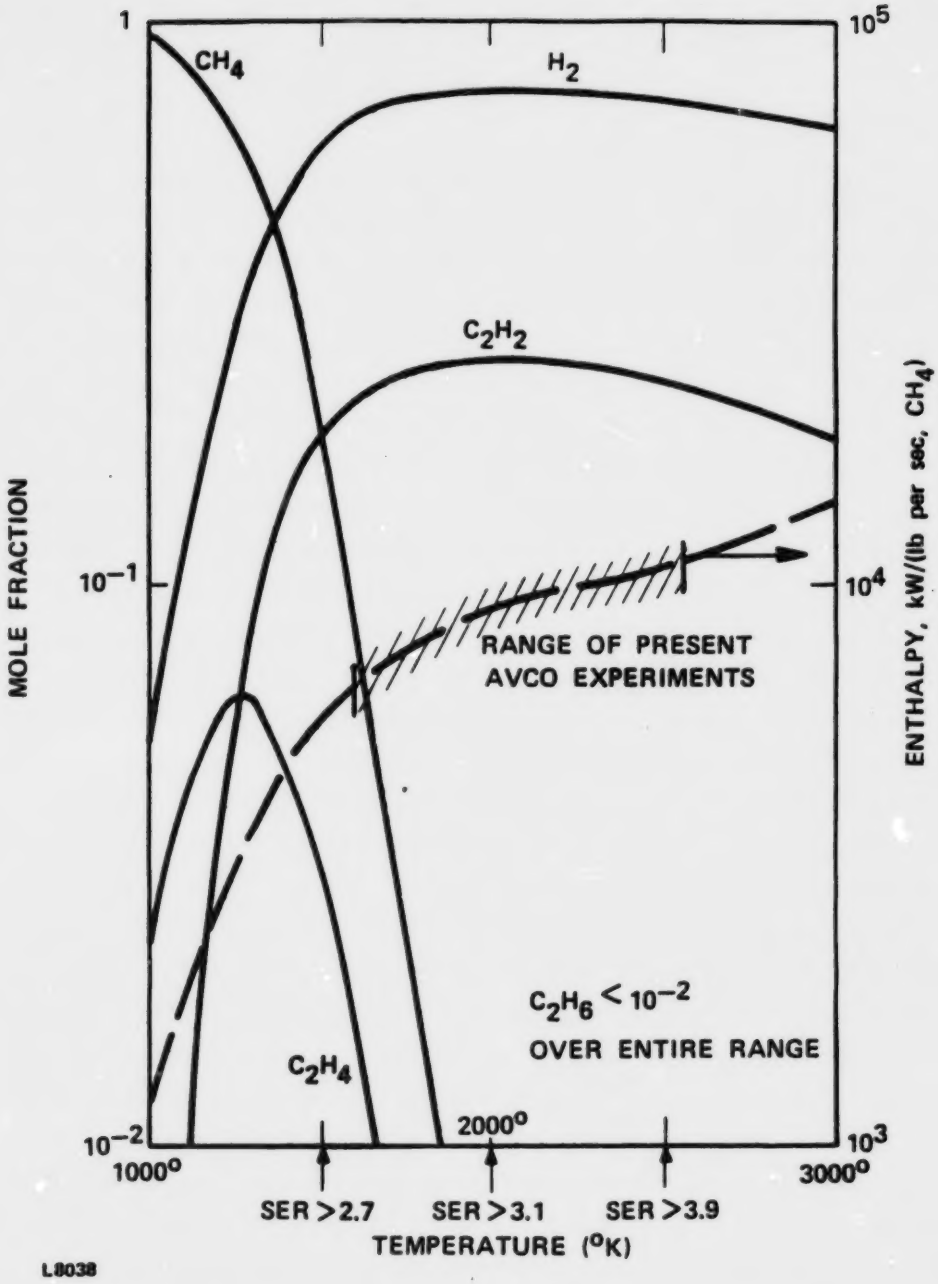


Figure 1-1 Arc Acetylene Process Gas Composition and Enthalpy vs Temperature, CH_4 Feed, 1 atm Pressure. (For clarity, only the major species of interest for the process are shown.)

3.5 kW-hr / lb C_2H_2, yield > 90 percent, and concentration of C_2H_2 > 10 percent. With ethane quench, we project (based on acetylene and ethylene yeild), SER of 2.5 kW-hr/lb of C_2H_2 and C_2H_4, yield > 90 percent, and concentration of C_2H_2 and C_2H_4 > 20 percent.

This report is divided into four sections. Section 1.0 is the Introduction. Section 2.0 describes the experimental equipment, and describes the work under Task I.0 (Design Modification), 2.0 (Equipment Reassembly), and 3.0 (Shakedown Runs) of the Statement of Work. Section 3.0 presents results and discussion, and describes the work under Tasks 4.0 (Experimental Matrix Study), 5.0 (Data Analysis), 6.0 (Duplicate Points), 8.0 (Model Utilization), and 9.0 (Optimum Conditions). Section 4.0 presents our projections on process performance with scaled-up reactors, corresponding to Task 10.0 (Scale-up Criteria). Tasks 7.0 (Problem Areas) and 11.0 (Cost Analysis) were the responsibility of SNC. Task 12.0 (Reports) has been fulfilled in the form of monthly reports and this Final Report.

For further understanding and development of the process, we recommend (in order of increasing level of effort) the following:

- Spatially resolved sampling of species distribution in the reactor
- Detailed modeling of the reactor (discharge, flow field, kinetics), using Avco's existing aerothermal codes as points of departure
- Scaled-up testing at the 1-8 MW level.

2.0 EXPERIMENTAL EQUIPMENT

The experiments to explore the feasibility of converting natural gas to acetylene were performed in a facility originally designed to investigate the arc process for conversion of coal to acetylene at small scale.

For the subject test program, the facility and the reactor were modified to accommodate controlled flows and mixtures of natural gas (CH_4), ethane (C_2H_6) and hydrogen, either as primary feed or quench. A storage manifold and feed lines to the reactor were installed. The gas-metering system and the controls were adapted to the new requirements. The reactor was operated at a nominal power of 100 kW (actual range 80-120 kW, depending on test conditions).

2.1 SAFETY AND ENVIRONMENTAL CONSIDERATIONS

The 100-kW Arc Reactor was engineered with a system of safety procedures, safety interlocks and checks, and a reliable product and waste disposal system. The primary concerns were related to the hazardous nature of the feedstocks (hydrogen, methane, ethane), the process stream (hydrogen, acetylene, and other combustibles) and treatment of waste streams with the potential of dissolved combustible gases.The safety system incorporated into the facility comprised combustible gas detectors, process stream monitors for air leakage into the system, combined with positive ventilation of the reactor room and explosion-proof wiring of the facility. Interlocks were provided such that safety criteria were satisfied prior to introducing combustible materials into the reactor systems with automatic system shutdown upon violation of any of the safety criteria. Checkout of the safety system was performed by conducting tests with inert feedstock and systematic violation of safety parameters.

2.2 FACILITY DESCRIPTION

The modified 100-kW Avco facility is designed to investigate various aspects of the arc process using a gaseous feedstock. It incorporates a subscale rotating arc reactor, described in detail in subsection 2.5, with the necessary controls, metering devices and diagnostics to allow measurement of

process efficiency and sensitivity to operating parameters. In the process to be explored, a gas such as CH_4 is fed into a rotating arc reactor, where it is heated to sufficiently high temperature that the most stable hydrocarbon produced is acetylene. The product stream passes through a primary quench zone where suitable quench may be injected, and through a second water quench, where its temperature is quickly decreased. The gaseous stream passes through a vacuum pump and then through an external stack, where it is burned as it vents to atmosphere.

For ease of discussion, the 100-kW Arc Reactor facility has been broken down into a series of subsystems, which are described in the following pages.

The main portion of the 100-kW facility is located within the reactor room, which has been designated for safety precautions as a Class 1, Division 2, Group A, B and D area. All electrical wiring in this area has been restructured to conform to a requirement of a hazardous area in conformance with the National Electrical Code. The walls of the reactor room have been sealed to prevent leakage from this area into adjacent rooms.

The reactor room walls are constructed of concrete block, and the exterior wall is fire-rated. The reactor room is protected with a sprinkler system and can be viewed from the control room through a safety window.

2.3 REACTOR POWER

The dc power for the 100-kw Arc Reactor facility is provided by a Perkin dc rectifier, with a rated output of 500 kW. The output of the rectifier can be used in either of two laboratories by proper arrangement of linkage at the link panel located in a separate room. Manually operated knife switches are located in each leg of the dc power. The negative lead passes through a water-cooled coil located within an oscillator circuit as is shown in the wiring schematic (Figure 2-1) and is then connected to the arc cathode. The positive lead from the power supply passes through the link panel, knife switch, and a calibrated shunt before attachment to the arc anode. Arc current is determined by measuring the voltage drop across the calibrated shunt, while arc voltage is measured with a voltmeter connected across the arc cathode and anode. (This voltmeter may be isolated from the circuit.)

Power to the arc magnetic field coil is obtained from a Miller dc Welder Power Supply. Leads from this power supply are connected through manually operated knife switches to the water-cooled arc field coil.

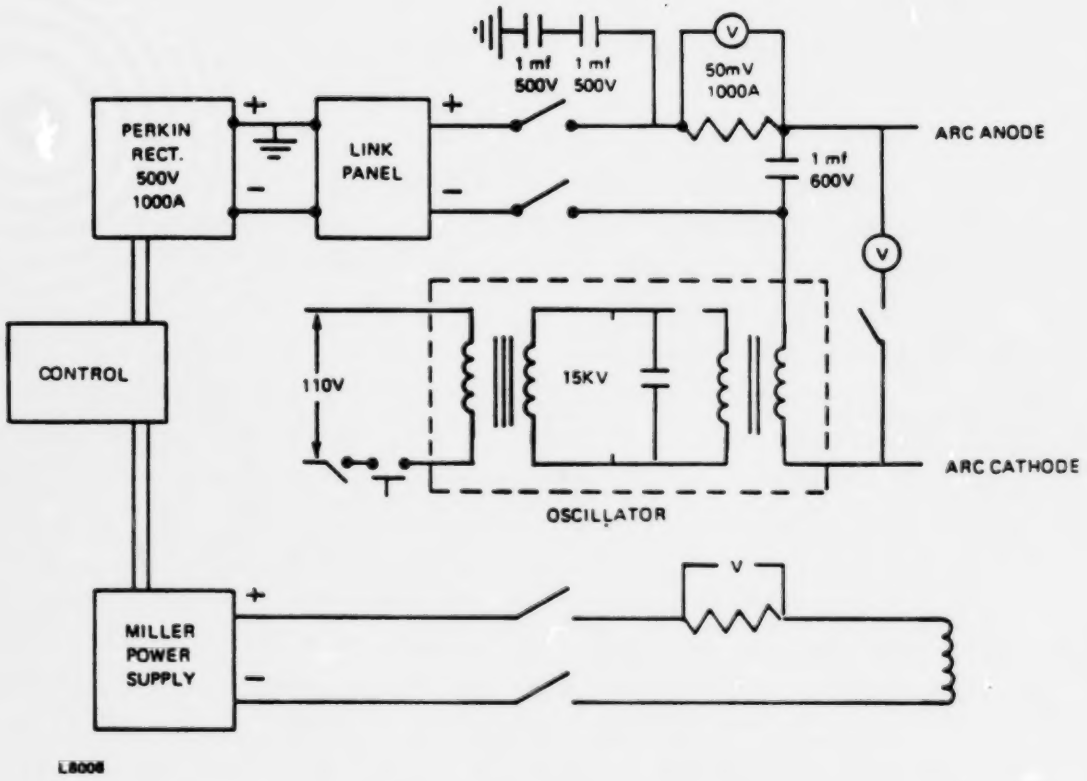


Figure 2-1 100 kW Arc Reactor System Power Circuits

The wiring diagram also includes a schematic of the oscillator circuit which is employed in generating a high-voltage radio-frequency discharge across the anode-cathode gap, thereby initiating the arc. When 110 Vac power is introduced into the oscillator, the 15,000-volt output from the transformer produces a spark between the oscillator electrodes. This in, turn, produces a high, radio-frequency voltage between the arc heater cathode and anode, causing a stable arc discharge to occur between these two points.

2.4 GAS SUPPLY SYSTEM

The gas storage consists of three independent systems located on a concrete pad outside the building (Figure 2-2). Two of the systems may be used for feedstock; one is reserved for nitrogen. The primary uses of nitrogen are for initial arc-starting procedure, arc shutdown, and as a pressurant for the dome regulators used in adjusting gas flow for all three gas streams. The flow passes through a regulator which, reduces the gas pressure to 150 psi and then through a normally closed solenoid valve, which can be activated from the reactor control console. The gas then passes into the gas manifold located within the reactor room through the nitrogen-powered dome regulators that control gas flow to various reactor components. Each of these streams is provided with a calibrated sonic orifice flow meter and a normally closed air-operated ball valve. These spring return-air-operated shutoff valves are activated by switches located within the reactor control console.

As shown in the gas supply schematic, two supply streams can be operated independently to provide control of gas flow to the cathode sheath, wall, and quench stream injection ports.

In normal operation, the arc heater is started with nitrogen flowing through the system This is accomplished by opening the main nitrogen valve, thereby allowing nitrogen into the gas manifold. The nitrogen pressure in the manifold can be adjusted using the pressure and relief regulator. Nitrogen flow through the various lines can then be adjusted independently.

Orifice plates used in determining the gas flow rates to the reactor are calibrated with precision variable area flow meters.

2.5 ARC REACTOR SYSTEM

The arc reactor system consists of two major components: the arc reactor itself and an arc reactor separation tank, as shown schematically in Figure 2-3.

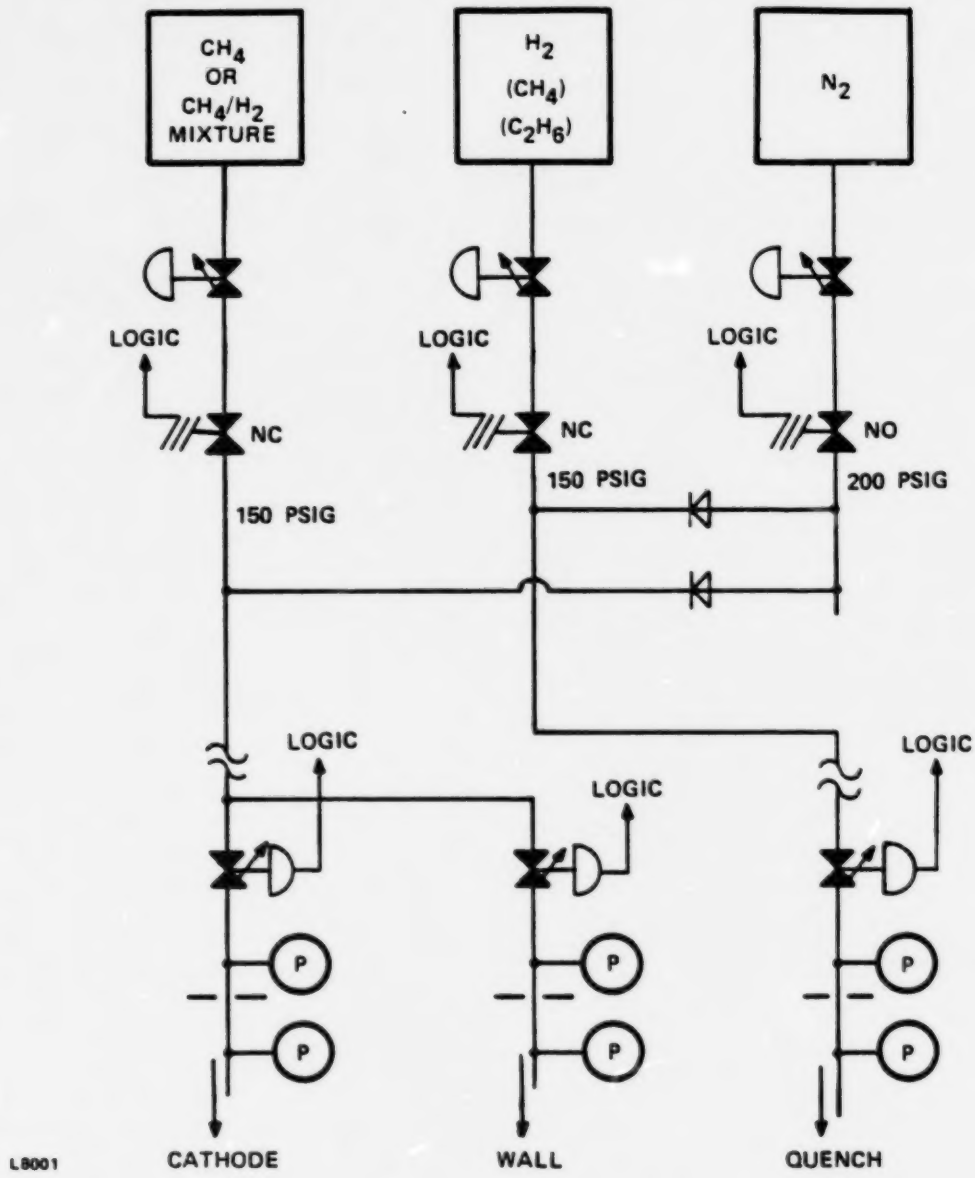


Figure 2-2 Gas System

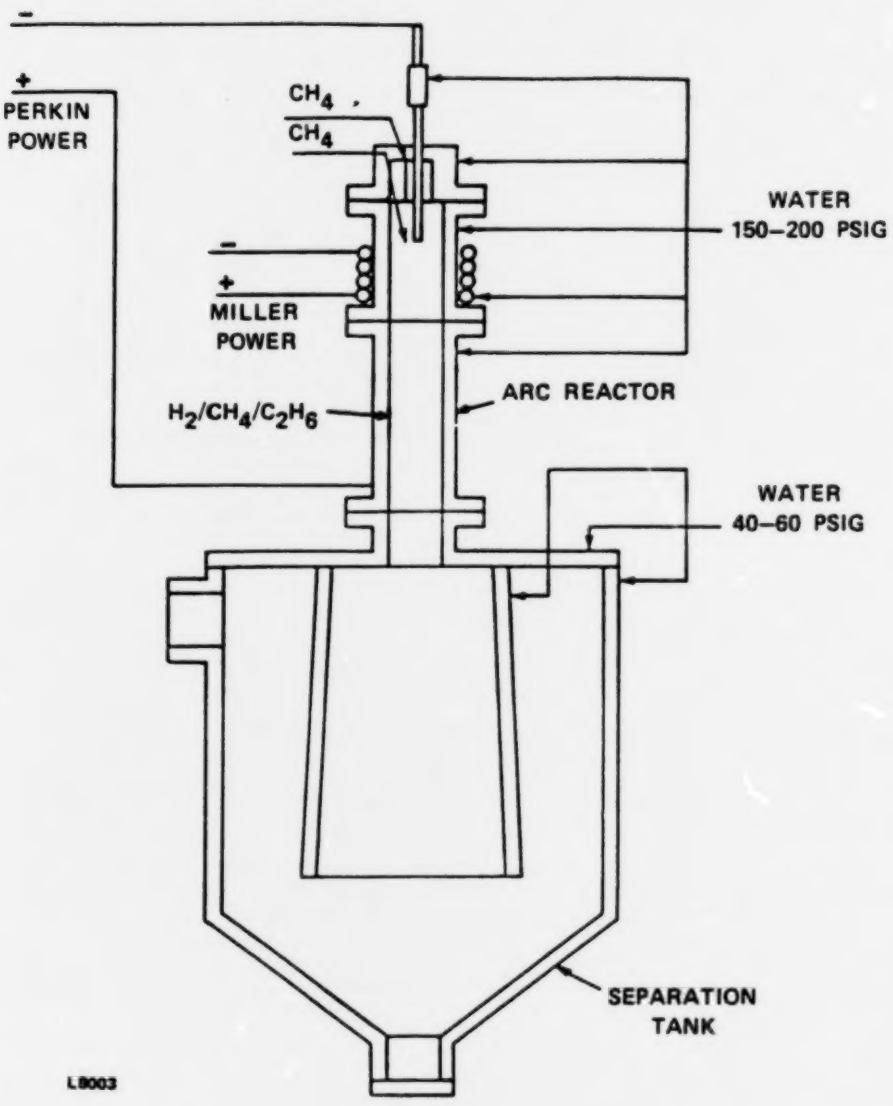


Figure 2-3 Arc Reactor Schematic

2.5.1 Arc Reactor

Basically, the arc reactor consists of a cathode, a cathode housing, an anode, a magnetic field coil, and an arc extension. Except for insulators within the arc heater assembly, all portions of the arc reactor are water-cooled with high-pressure water.

Gas feed to the arc reactor occurs at several locations. The main gas feed is through the cathode sheath injection ports; this stream surrounds the cathode with a protective layer. The other portion of the gaseous feed enters the reactor through a second set of concentric injection ports located at the rear wall of the anode. The remainder of the gas feed can be introduced into the reactor through quench ports located downstream of the reactor anode.

The reactor is provided with a water-cooled field coil. This field coil creates a concentric magnetic field, causing the arc column to rotate, thereby moving the anode or root over the surface of the arc anode. This rotation distributes the heating at the arc root over a large area to prevent arc burn-out. Figure 2-4 shows the approximate distances between the arc termination and the first quench (No. 1) and the distance to the second quench (No. 2). The primary quench distance of 6 inches was reduced to 3 inches for the "short-anode" experiments described in Section 3.0.

2.5.2 Arc Reactor Separation Tank

Immediately downstream of the arc reactor is a double-walled, water-cooled tank that contains a water-cooled baffle. In the past, this water-cooled chamber served the purpose of providing some crude separation of solids from the process stream, when the facility was run with coal. Cooling water to the reactor separation tank is obtained from the city water manifold in the reactor room.

2.6 VACUUM PUMP SYSTEM

The vacuum pump system used in the 100-kW Arc Reactor facility consists of the following items:

- Vacuum pump
- Vacuum pump motor drive
- Water separator
- Flow control valves
- Auxiliary equipment

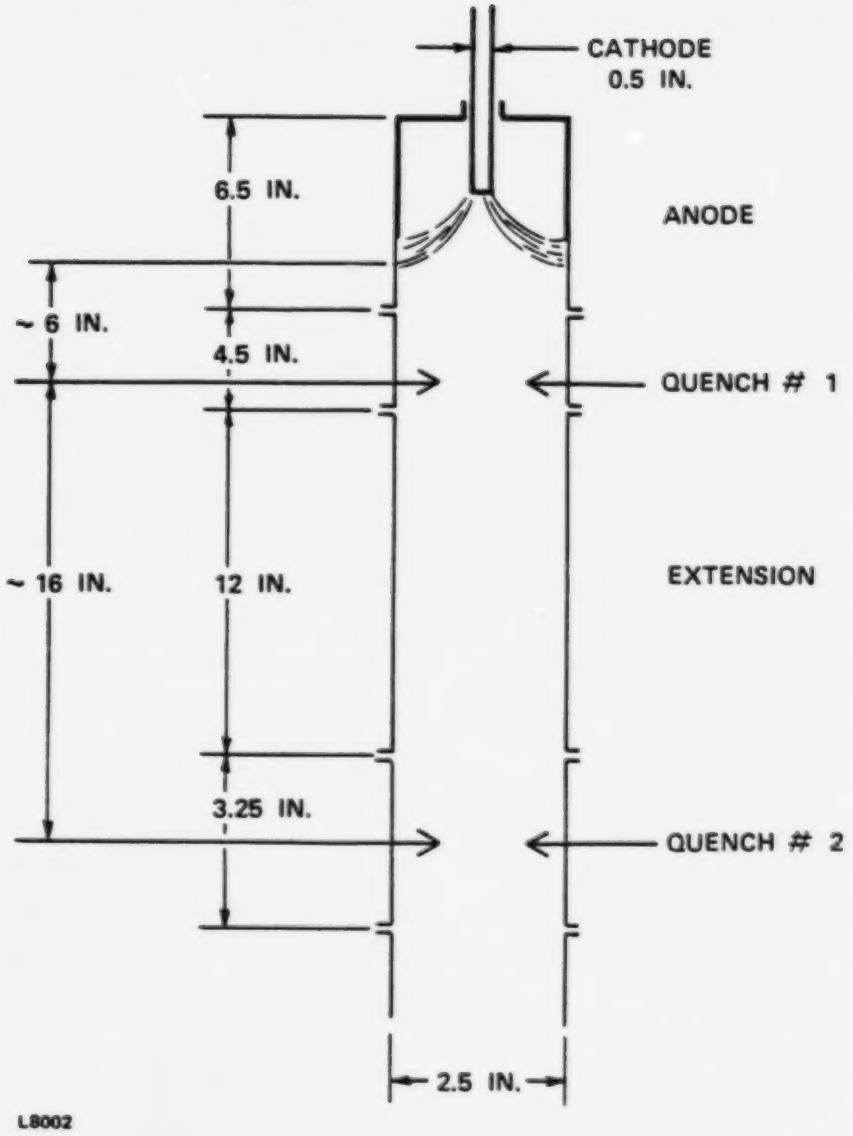


Figure 2-4 Arc Reactor Dimensions

The vacuum pump used in the 100 kW Arc Reactor system is a Nash CL-702 water ring vacuum pump, having a pumping capacity variation with inlet pressure as shown in Figure 2-5. The vacuum-pump water flow requirement of 15 gpm is provided from the high-pressure water manifold. Water flow to the pump is controlled by a hand valve and is set at the required flow using a rotameter. The vacuum pump is provided with inlet and outlet flow manifolds.

The vacuum pump motor drive is a GE Model SK 324CN205AP, 230/460 V, 3-phase 40-horsepower motor. The motor is rated by Underwriters Laboratory as satisfactory for Class I GR D and Class II, GR F&G facilities. The motor housing is rated for temperature code 38. The Underwriters Laboratory indicated that this motor would be satisfactory for a Class 1, Division II GR A and B installation if the thermal overload switch in the motor is not wired. The motor drive is connected to the vacuum pump shaft by a v-belt drive provided with a belt guard.

Immediately downstream of the vacuum-pump outlet manifold is a water flow separator, used to separate the pump compressant from the process stream. The vacuum-pump waste water is transferred to a holding tank for treatment prior to entering a sanitary drain.

Both the bypass and vacuum-pump exhaust lines are provided with air-operated, normally closed ball valves. The pressure in the system upstream of the vacuum pump is controlled with an adjustable ball valve. The opening of the throttling valve is adjustable between the full-open and full-closed position by varying the pressure to the valve air operator. This pressure is controlled by a hand-operated pressure and relief regulator on the arc control console. Adjustment of the throttling valve opening allows the arc reactor pressure to be varied between 0.10 and 0.5 atmosphere.

Auxiliary equipment for the vacuum pump system includes an Allen-Bradley, Reduced Voltage Starter for the vacuum pump motor, pump compressant flow valve, and a compressant flow rotameter.

When operating the vacuum pump system, the procedure used is as follows. With pressure in the shop air manifold, operation of the upstream and downstream air-operated ball valves is checked by closing the appropriate switches on the arc control console. Operation of the 2-inch throttling valve is checked by varying the operating pressure with the hand regulator on the control console. After satisfactory valve operation is obtained, water flow

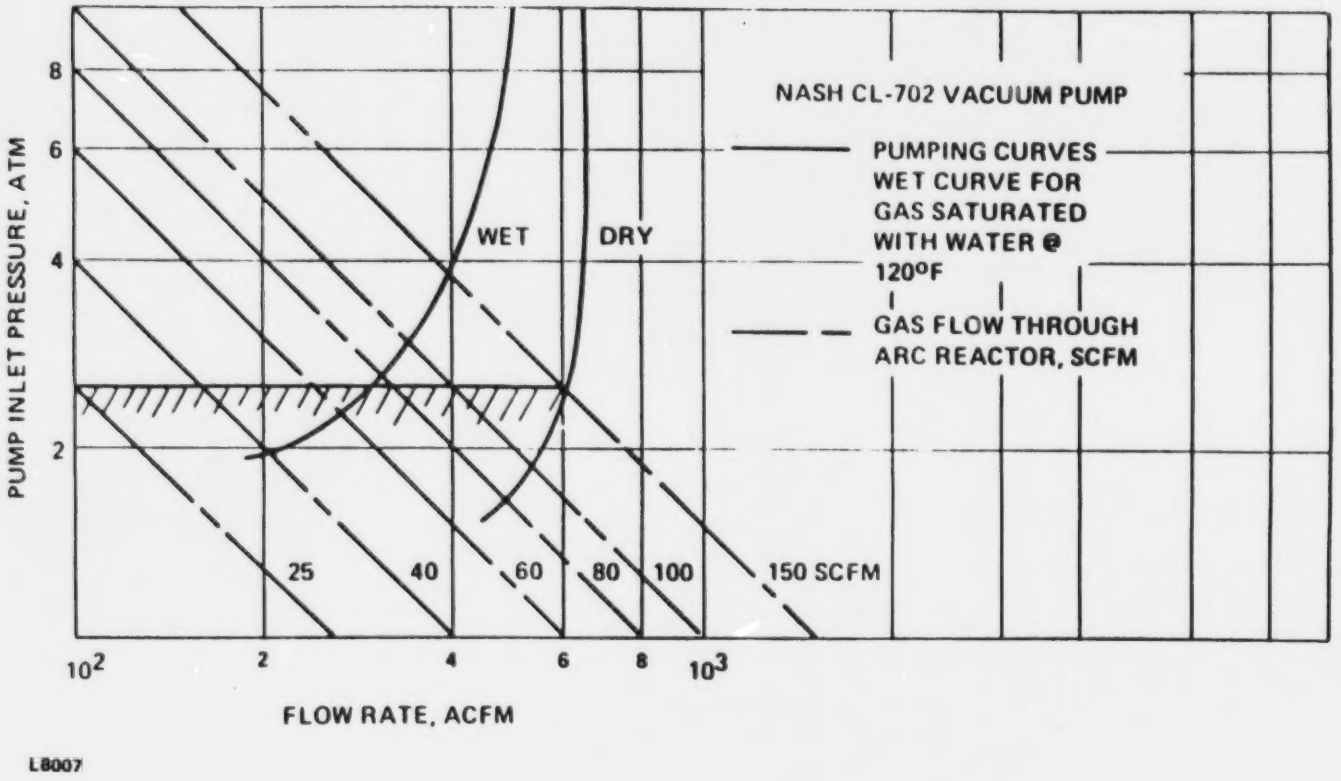


Figure 2-5 Vacuum Pump Operating Characteristics

AVCO EVERETT

to the pump is obtained by opening the water manifold shutoff valves; compressant flow at this time will be less than the desired flow of 15 gpm. The required compressant flow is obtained by starting the water pumps and adjusting the vacuum pump water flow rate to the required value. At this time, the inlet and outlet valves in the process line are opened. The vacuum pump is then started by depressing the start switch on the Allen-Bradley Reduced Voltage Starter in the reactor control room. With no gas through the system, the pump inlet pressure decreases rapidly to reach a steady-state value of 27 in. Hg vacuum.

The waste slurry pump is a Wilden Model M-4 air-operated double-diaphragm pump. The pump is operated between the high- and low-water level set points by the liquid level controller. This was initially chosen for the coal-based facility, and would be replaced by a conventional centrifugal pump for CH_4 feed acetylene reactor configuration.

2.7 FLARE GAS IGNITION SYSTEM

The flare gas ignition system consists of a propane gas supply for a pilot flame, an exhaust stack located on the roof area above the reactor room, and a process vent line extending into the exhaust stack. This system provides a means of burning the process stream as it exhausts to the atmosphere.

The pilot is obtained from a rectification-type pilot burner that incorporates a pilot nozzle with alloy grounding fins, spark plug, flame rod, propane gas regulator and air-mixing chamber.

Spark ignition of the premixed propane-air stream entering the pilot burner is obtained from an ignition transformer, which is activated by a Protection Controls Protectifier Ignition Control System, Model 76057-B. In the present system, both the air and propane solenoid valves are wired across Terminals 2 and 3. A key switch in the control console is used to shut off power to the ignition system and pilot burner. This switch is provided to eliminate the possibility of ignition system operation while personnel are engaged in stack maintenance.

The stack, located on the roof above the reactor room, is 4 feet in diameter and extends 18 feet above the roof level. The base of the stack is 3 feet above the roof, thereby providing the air inlet required for combustion

of the process exhaust gases. The stack serves a twofold purpose in that it protects the flare from wind and also prevents personnel injury that could occur with an open flame. The roof area immediately around the stack is cordonned, with warning signs and visual alarms, to inform personnel who may be working on the roof as to the hazardous nature of the stack GR A, B, CD and CL II, Div 1, 2, GREFG housing.

2.8 METHOD OF CHEMICAL ANALYSIS

A Hewlett-Packard Model 5834A gas chromatograph was used for chemical analysis of the arc-acetylene process gas. The instrument was equipped with both flame ionization (FID) and thermal conductivity (TCD) detectors. For this study, the TCD detector was used exclusively because it was responsive to all components in the gas stream, including the argon tracer. Total gas flowrate was obtained by means of the tracer-gas technique in which a tracer gas (argon) was bled into the process line at a controlled rate. The resulting gas mixture was analyzed, and the total flowrate was calculated from the tracer gas concentration. The sample was drawn upstream of the vacuum pump.

The 5834A is a microprocessor-controlled chromatograph with programmable valve operation to control the flow of sample through three GC columns. The first column (Column I) actually consists of two GC columns in series, a Bis-adipate liquid phase on a Chromosorb support, followed by a column packed with DC-200 Silicone oil on Chromosorb. This column can be used to separate propylene, acetylene, carbonyl sulfide, hydrogen sulfide, and methyl acetylene. It is then backflushed to drive off hydrogen cyanide, water, carbon disulfide and the higher acetylenic compounds. A column packed with Porapak Q (Column II) is used to separate ethylene and carbon dioxide. Finally, a 5A Molecular Sieve column (Column III) is used to separate hydrogen, argon, nitrogen, methane and carbon monoxide. The flow of carrier gas through the system as the programmed valves are operated during the run is shown schematically in Figure 2-6. The sampling system is shown schematically in Figure 2-7. The analysis system described was designed initially for previous arc-coal acetylene tests. The gas samples in this study were analyzed for hydrogen, argon, nitrogen, acetylene, methane, ethane and ethylene. The carrier gas was helium and the column oven was maintained at 50^{o}C. The existing system provided a complete analysis with a single injection for all components in the process stream.

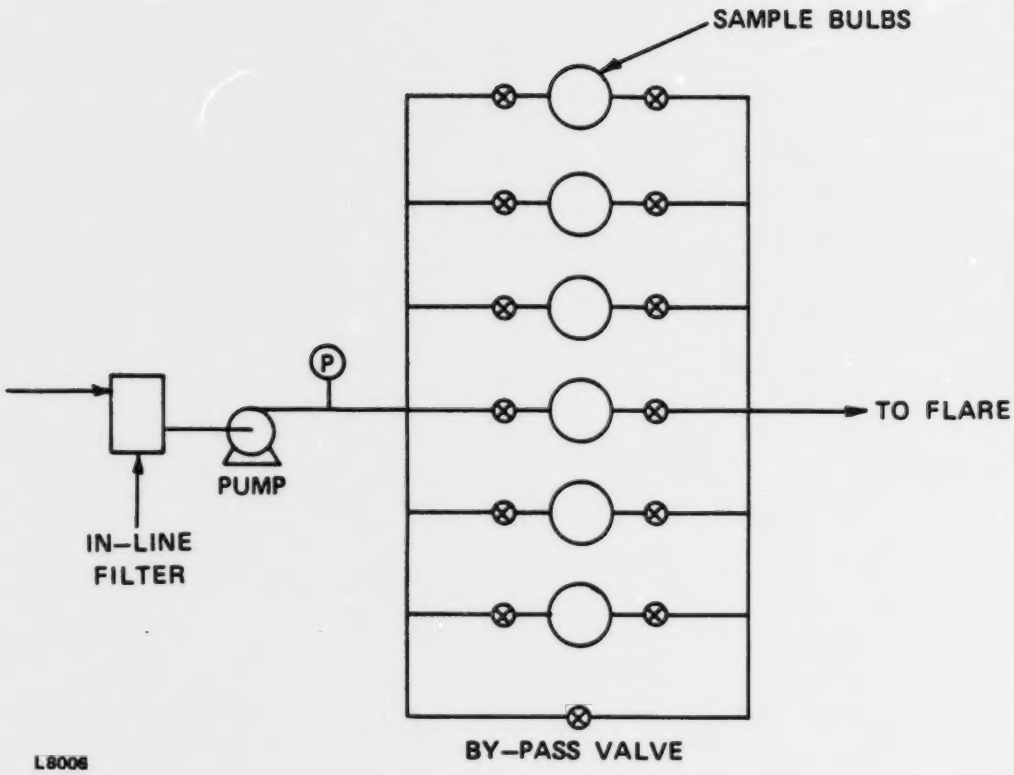


Figure 2-6 Sampling System

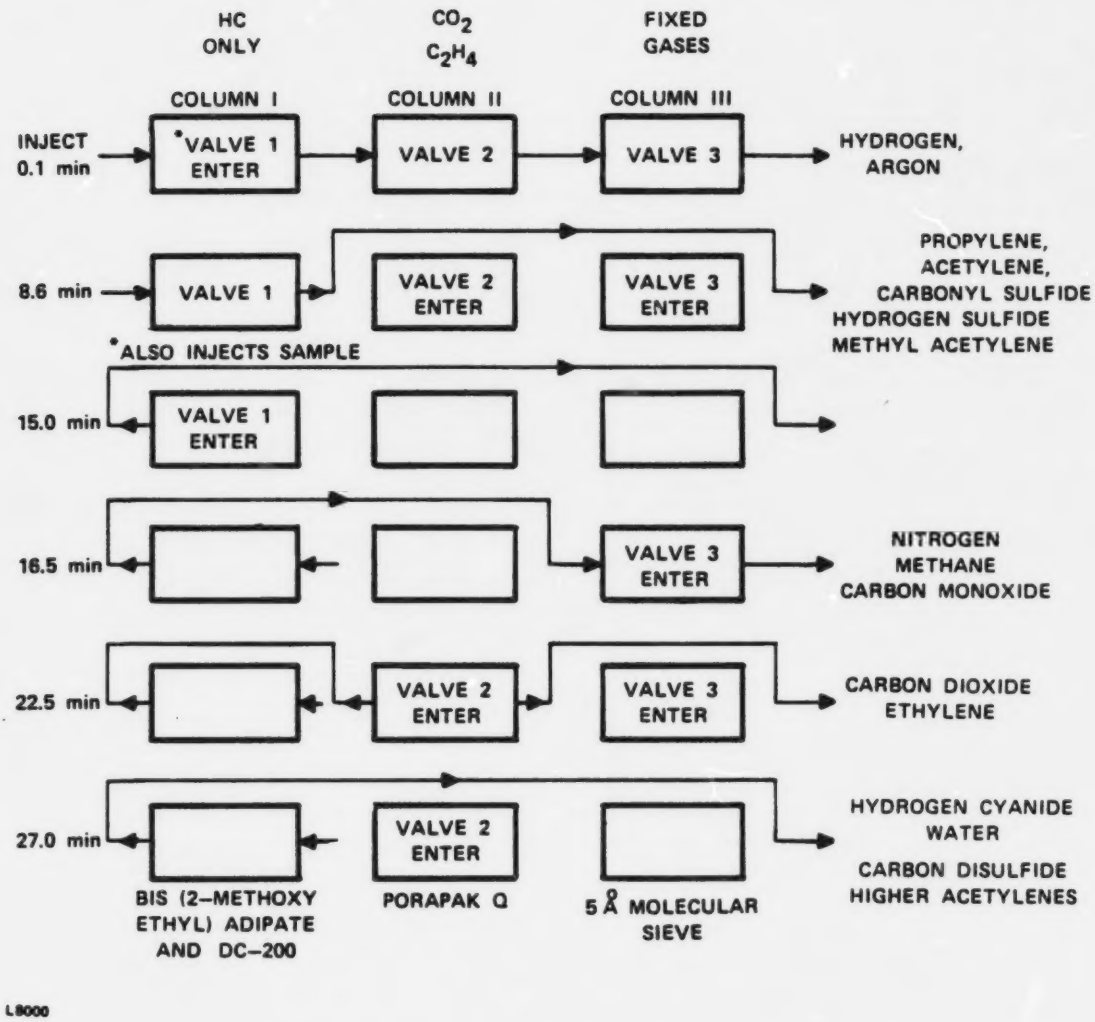


Figure 2-7 Gas Chromatograph System

Particulate matter was removed from the samples with tubular glass filters. These filters, obtained from Balston, Inc. had efficiencies greater than 99.99 percent for particles in the 0.3-0.6 micron range. Since the reactor operated under subatmospheric pressures, it was necessary to use a pump in the sample line to drive the process gas. A total of six separate samples could be collected during one run.

A gas injection system was constructed for the introduction of gas samples into the GC. In this system, the outlet of the GC sample loop was connected through shutoff and control valves to a vacuum pump. Pressure in the sample loop was monitored by an MKS pressure transducer calibrated for 0-1000 mm Hg. Calibration of this transducer was checked periodically and it was found to be accurate to within +0.1 mm Hg at low (~ 10 mm Hg) pressures and within $\pm$1 percent of reading at higher pressures. The inlet side of the sample loop was connected to a manifold, which included a Cajon vacuum fitting for connection of filled sample bottles and input connections, with appropriate shutoff and control valves for introduction of the various calibration standards. A 0.25-ml sample loop was used for all the analyses. This injection system allowed for ease of injection of process-gas samples, which were collected and stored at approximately atmospheric pressure and for accurate determination of the pressure in the sample loop. Accuracy in pressure measurement was required for correct quantitative results and for varying the amounts of standard gases injected for calibration purposes.

A set of Matheson certified gas mixtures was obtained to provide calibration standards and response factors for all components expected in the arc-acetylene process gas, and calibrations were performed frequently to ensure accuracy in the results. Although tests showed a linear response of the TCD to a wide range of concentrations of the major components of the process stream (except hydrogen), care was taken to make calibration runs for acetylene and argon with concentrations close to those found in actual process gas samples. Accuracy in the determination of these components was necessary for accurate calculation of acetylene yield for evaluation of the process. Hydrogen, except in lower concentrations than those found in these samples, always gives a nonlinear response to the TCD when helium is used as the carrier gas. In this study, the concentrations of all components except hydrogen were determined by the GC with the appropriate correction factor applied for differences in sample loop pressure. Hydrogen was obtained by difference as the balance of the gas sample.

3.0 RESULTS AND DISCUSSION

In studying the feasibility of producing acetylene from natural gas by the electric arc process, three critical parameters must be determined: the yield (Y) of acetylene from natural gas, the specific energy requirement (SER) to produce 1 lb of acetylene and the concentration (C) of acetylene in the product gases. The purpose of this study is to designate the operating conditions at which these critical parameters are optimum.

The process variables studied are the feed gas composition and flowrate; the nature, flowrate, and injection point of quench; and the system pressure. The power input was not varied as an independent variable; it was adjusted as required from experiment to experiment to maintain a stable arc. This was done by maintaining the current at 300 A and changing the voltage to obtain a stable arc at the designated system pressure for the experiment.

The main product of processing natural gas in an arc reactor is acetylene. However, an appreciable amount of ethylene is also produced, especially when ethane is used as the quench. Ethylene is a valuable product and hence some credit should be given to its production, in the definition of the three critical parameters discussed above. Second, this process has two input streams: feed and quench. It is therefore important to clearly reflect the presence of the two streams in the critical parameters.

Yield - In this study, two types of yields are discussed. First, yield of acetylene based on feed gas. This value is defined as:

$$Y_1 = \frac{\text{Carbon in } C_2H_2}{\text{Carbon in Feed}}$$

The second definition is yield of acetylene and ethylene based on both feed and quench. This is given by:

$$Y_2 = \frac{\text{Carbon in } C_2H_2 + C_2H_4}{\text{Carbon in Feed + Quench}}$$

Specific Energy Requirement (SER) - Again two SERs are defined, one based on the energy required to produce 1 lb of acetylene:

$$SER_1 = \frac{\text{Power input}}{\text{lb of } C_2H_2} \quad \frac{\text{kW-hr}}{\text{lb } C_2H_2}$$

and the other based on the power required to produce a pound of acetylene plus ethylene.

$$SER_2 = \frac{\text{Power input}}{\text{lb of } C_2H_2 + C_2H_4} \quad \frac{\text{kW-hr}}{\text{lb } (C_2H_2 + C_2H_4)}$$

Concentration - The two definitions are: C_1=molar percent of C_2H_2 in product gas, and C_2 = molar percent of $C_2H_2 + C_2H_4$ in product gas.

The reactor is externally cooled by circulating water. Thermocouples are located along the sides of the reactor to measure the temperature of the cooling water. These measurements allow the computation of the thermal loss along the reactor. First impressions may lead one to believe that the SERs should be calculated based on the net power input; i.e., total power input minus the thermal loss. This would, however, be incorrect as the electric energy is first transferred to the feed gas, which later loses heat to the walls (~ 30-40 percent before the water quench; Figure 2-4). As the reactions are very fast, most of the conversion occurs before much heat loss occurs; therefore, the power required for the reaction to occur is closer to the total power input and not to the net power input. For conservatism, the SERs are based on the total power input. Nonetheless, the basis of Avco's previous experience with scaling the arc-coal process to 1 MW, we would expect the scale-up SER values to be slightly lower than those presented in this section (as discussed in Section 4.0 on process scale-up projections).

3.1 MATRIX STUDY

A matrix study was conducted to determine the effect of the process variables on the critical parameters. Table 3-1 gives the operating conditions employed. The results are shown in Tables 3-2 to 3-7. The carbon closure shown in these tables gives an indication of the extent of soot formation

TABLE 3-1

ARC ACETYLENE FROM NATURAL GAS TEST MATRIX

Test No.	Feed Type	Feed Flowrate (SCFM)	Quench Type	Quench Flowrate (SCFM)	Arc Current (A)	Reactor Pressure (mmHg)
1	CH_4	10.4	H_2	32	300	101
2	CH_4	13.0	H_2	32	300	110
3	CH_4	13.9	H_2	32	300	118
4	CH_4	18.7	H_2	32	300	126
5	CH_4	22.0	H_2	32	300	133
6	CH_4	18.7	H_2	34.8	300	120
7	CH_4	18.7	H_2	24.9	300	113
8	CH_4	18.7	H_2	15.2	300	105
9	CH_4	18.7	H_2	0.0	300	92
10	CH_4	18.7	H_2	33.2	300	212
11	CH_4	18.7	H_2	33.2	300	330
12	CH_4+H_2	17.5	H_2	33.2	300	65
13	CH_4+H_2	23.1	H_2	33.2	300	125
14	CH_4+H_2	27.4	H_2	33.2	300	135
15	CH_4+H_2	30.9	H_2	33.2	300	143
16	CH_4+H_2	27.4	H_2	33.2	300	215
17	CH_4+H_2	27.4	H_2	33.2	300	300

TABLE 3-1 (CONCLUDED)

ARC ACETYLENE FROM NATURAL GAS TEST MATRIX

Test No.	Feed Type	Feed Flowrate (SCFM)	Quench Type	Quench Flowrate (SCFM)	Arc Current (A)	Reactor Pressure (mmHg)
18	CH_4	13.8	CH_4	5.2	300	80
19	CH_4	18.7	CH_4	5.2	300	90
20	CH_4	18.7	CH_4	10.4	300	100
21	CH_4	18.7	CH_4	15.5	300	106
22	CH_4	18.7	C_2H_6	5.04	300	93
23	CH_4	18.7	C_2H_6	7.92	300	100
24	CH_4	18.7	C_2H_6	5.04	300	200
25	CH_4	18.7	C_2H_6	7.92	300	215
26	CH_4	18.7	C_2H_6	5.04	300	300
27	CH_4	18.7	C_2H_6	7.92	300	300
28*	CH_4	18.7	C_2H_6	5.04	300	92
29*	CH_4	18.7	C_2H_6	7.92	300	100
30*	CH_4	18.7	C_2H_6	5.04	300	205
31*	CH_4	18.7	C_2H_6	7.92	300	210
32*	CH_4	18.7	C_2H_6	5.04	300	330
33*	CH_4	18.7	C_2H_6	7.92	300	315

*Short anode runs.

TABLE 3-2

VARYING CH_4 FEED + FIXED H_2 QUENCH

Test No.		1	2	3	4	5
Exp. Run		7-2	7-3	10-2	10-3	10-4
Pressure	mm Hg	101	110	118	126	133
Power Input	kW	80	88	90	100	103
Feed Gas	Type	CH_4	CH_4	CH_4	CH_4	CH_4
	SCFM	10.4	13.0	13.9	18.7	22.0
	10^{-3} lb/sec	7.2	8.9	9.6	12.9	15.2
Quench Gas	Type	H_2	H_2	H_2	H_2	H_2
	SCFM	32	32	32	32	32
	10^{-3} lb/s	3.1	3.1	3.1	3.1	3.1
Process Gas						
Ar	%	0.72	0.62	0.59	0.56	0.53
	SCFM	0.38	0.38	0.38	0.38	0.38
Total Flow	SCFM	56.8	61.3	64.4	67.9	71.7
C_2H_2	%	6.6	8.4	7.9	10.0	9.8
	SCFM	3.5	5.1	5.1	6.7	7.0
	10^{-3} lb/s	4.0	5.7	5.7	7.6	7.9
CH_4	%	5.0	3.2	4.4	5.6	8.0
	SCFM	2.6	2.0	2.8	3.8	5.7
	10^{-3} lb/s	1.8	1.35	1.9	2.6	4.0
C_2H_4	%	0.1	0.07	0.14	0.15	0.19
	SCFM	5.1×10^{-2}	4.5×10^{-2}	8.7×10^{-2}	9.8×10^{-2}	0.13
	10^{-3} lb/s	0.07	0.06	0.11	0.13	0.17
C_2H_6	%	—	—	—	—	—
	SCFM	—	—	—	—	—
	10^{-3} lb/s	—	—	—	—	—
H_2	%	86.3	86.5	86.6	82.7	80.5
	SCFM	45.7	52.7	55.8	56.1	57.6
	10^{-3} lb/s	4.0	4.6	4.8	4.8	5.0
N_2	%	1.3	1.2	0.4	1.0	1.0
Carbon Closure	%	97	98	97	97	94

TABLE 3-2 (CONCLUDED)

VARYING CH_4 FEED + FIXED H_2 QUENCH

Test No.	1	2	3	4	5
Exp. Run	7-2	7-3	10-2	10-3	10-4
H Closure %	98	102	105	97	97
Y_1 % (C in C_2H_2)/(C in feed)	70	81	75	75	66
Y_2 % (C in C_2H_2 + C_2H_4)/(C in feed + quench)	72	82	77	76	67
SER_1 (kW-hr/lb C_2H_2)	5.56	4.29	4.39	3.65	3.62
SER_2 (kW-hr/lb C_2H_2 + C_2H_4)	5.46	4.24	4.30	3.59	3.55

TABLE 3-3

CH_4 FEED + VARYING H_2 QUENCH

Test No.		6	7	8	9	10	11
Exp. Run		12-2	12-3	12-4	12-5	12-6	12-7
Pressure	mm Hg	120	113	105	92	212	330
Power Input	kW	88.5	85.0	81.1	76.0	97.5	112.5
Feed Gas	Type	CH_4	CH_4	CH_4	CH_4	CH_4	CH_4
	SCFM	18.7	18.7	18.7	18.7	18.7	18.7
	10^{-3} lb/s	12.9	12.9	12.9	12.9	12.9	12.9
Quench Gas	Type	H_2	H_2	H_2	H_2	H_2	H_2
	SCFM	34.8	24.9	15.2	0.00	33.2	33.2
	10^{-3} lb/s	3.02	2.16	1.32	0.00	2.88	2.88
Process Gas							
Ar	%	0.56	0.67	0.81	1.07	0.51	0.50
	SCFM	0.38	0.38	0.38	0.38	0.38	0.38
Total Flow	SCFM	67.8	56.7	46.9	35.5	74.5	76
C_2H_2	%	8.19	9.52	11.21	13.11	9.15	9.89
	SCFM	5.55	5.40	5.26	4.65	6.82	7.52
	10^{-3} lb/s	6.21	6.04	5.89	5.20	7.63	8.42
CH_4	%	7.79	9.98	13.10	23.33	6.68	3.51
	SCFM	5.28	5.66	7.43	8.28	4.98	2.67
	10^{-3} lb/s	3.64	3.91	5.13	5.72	3.94	1.84
C_2H_4	%	0.19	0.28	0.55	0.72	0.20	0.29
	SCFM	0.13	0.16	0.31	0.26	0.15	0.22
	10^{-3} lb/s	0.16	0.19	0.38	0.32	0.18	0.27
C_2H_6	%	—	—	—	—	—	—
	SCFM	—	—	—	—	—	—
	10^{-3} lb/s	—	—	—	—	—	—
H_2	%	82.09	77.99	72.59	59.88	82.69	85.63
	SCFM	55.6	44.2	41.2	21.3	61.6	65.1
	10^{-3} lb/s	4.82	3.83	3.57	1.85	5.35	5.65
N_2	%	1.18	1.56	1.74	1.89	0.77	0.18
Carbon Closure	%	92	92	102	100	104	100

TABLE 3-3 (CONCLUDED)

CH_4 FEED + VARYING H_2 QUENCH

Test No Exp. Run		6 12-2	7 12-3	8 12-4	9 12-5	10 12-6	11 12-7
H Closure	%	101	100	119	118	113	112
Y_1 (C in C_2H_2)/(C in feed)	%	61	59	58	51	75	83
Y_2 (C in C_2H_2 + C_2H_4)/(C in feed + quench)	%	63	61	61	54	77	85
SER_1 (kW-hr/lb C_2H_2)		3.96	3.91	3.82	4.06	3.55	3.71
SER_2 (kW-hr/lb C_2H_2 + C_2H_4)		3.86	3.79	3.59	3.82	3.47	3.60

TABLE 3-4

MIXED CH_4 PLUS H_2 FEED + H_2 QUENCH

Test No		12	13	14	15	16	17
Exp. Run		14-2	14-3	14-4	14-5	14-6	14-7
Pressure	mm Hg	65	125	135	143	215	300
Power Input	kW	82.2	91.5	97.5	107.4	105.0	121.5
Feed Gas	Type	80% CH_4 + 20% H_2 (volume basis)					
	SCFM	17.5	23.1	27.4	30.9	27.4	27.4
	10^{-3} lb/s	10.0	13.2	15.6	17.6	15.6	15.6
Quench Gas	Type	H_2	H_2	H_2	H_2	H_2	H_2
	SCFM	33.2	33.2	33.2	33.2	33.2	33.2
	10^{-3} lb/s	2.88	2.88	2.88	2.88	2.88	2.88
Process Gas							
Ar	%	0.62	0.55	0.49	0.47	0.48	0.46
	SCFM	0.38	0.38	0.38	0.38	0.38	0.38
Total Flow	SCFM	61.3	69.1	77.6	80.9	79.2	82.6
C_2H_2	%	6.99	8.23	8.59	8.67	9.07	9.37
	SCFM	4.28	5.68	6.66	7.01	7.18	7.73
	10^{-3} lb/s	4.79	6.36	7.45	7.85	8.04	8.65
CH_4	%	4.99	5.65	7.05	8.30	5.88	4.34
	SCFM	3.05	3.90	5.47	6.71	4.65	3.58
	10^{-3} lb/s	2.11	2.69	3.78	4.64	3.21	2.47
C_2H_4	%	0.11	0.18	0.17	0.31	0.16	0.18
	SCFM	0.06	0.12	0.13	0.25	0.13	0.15
	10^{-3} lb/s	0.08	0.15	0.16	0.30	0.16	0.18
C_2H_6	%	—	—	—	—	—	—
	SCFM	—	—	—	—	—	—
	10^{-3} lb/s	—	—	—	—	—	—
H_2	%	86.74	84.88	82.30	80.99	83.24	85.35
	SCFM	53.17	58.65	63.86	65.52	65.92	70.50
	10^{-3} lb/s	4.62	5.09	5.55	5.69	5.73	6.12
N_2	%	0.55	0.51	1.40	1.26	1.17	0.30
Carbon Closure	%	86	86	89	88	91	91

TABLE 3-4 (CONCLUDED)

MIXED CH_4 PLUS H_2 FEED + H_2 QUENCH

Test No Exp. Run	12 14-2	13 14-3	14 14-4	15 14-5	16 14-6	17 14-7
H Closure %	100	98	101	99	102	105
Y_1 % (C in C_2H_2)/(C in feed)	63	63	62	58	67	73
Y_2 % (C in C_2H_2 + C_2H_4)/(C in feed + quench)	64	64	64	60	69	74
SER_1 (kW-hr/lb C_2H_2)	4.77	4.00	3.64	3.80	3.63	3.90
SER_2 (kW-hr/lb C_2H_2 + C_2H_4)	4.69	3.90	3.56	3.66	3.56	3.82

TABLE 3-5

CH_4 FEED + CH_4 QUENCH

Test No.		18	19	20	21
Exp. Run		11-2	11-3	11-4	11-5
Pressure	mm Hg	80	90	100	106
Power Input	kW	73.5	74.4	78.0	81.0
Feed Gas	Type	CH_4	CH_4	CH_4	CH_4
	SCFM	13.8	18.7	18.7	18.7
	10^{-3} lb/s	9.5	12.9	12.9	12.9
Quench Gas	Type	CH_4	CH_4	CH_4	CH_4
	SCFM	5.2	5.2	10.4	15.5
	10^{-3} lb/s	3.6	3.6	7.2	10.7
Process Gas					
Ar	%	1.29	1.09	1.03	0.82
	SCFM	0.38	0.38	0.38	0.38
Total Flow	SCFM	29.5	34.9	36.9	46.3
C_2H_2	%	13.9	12.9	11.9	10.9
	SCFM	4.1	4.50	4.39	5.05
	10^{-3} lb/s	4.59	5.04	4.91	5.65
CH_4	%	31.2	36.6	41.3	45.7
	SCFM	9.20	12.8	15.2	16.9
	10^{-3} lb/s	6.36	8.84	10.5	11.7
C_2H_4	%	0.46	0.71	0.60	0.52
	SCFM	0.14	0.25	0.22	0.19
	10^{-3} lb/s	0.17	0.30	0.27	0.23
C_2H_6	%	—	—	—	—
	SCFM	—	—	—	—
	10^{-3} lb/s	—	—	—	—
H_2	%	51.4	46.9	43.3	40.7
	SCFM	15.2	16.4	16.0	18.8
	10^{-3} lb/s	1.32	1.42	1.39	1.63
N_2	%	0.99	1.78	1.86	1.44
Carbon Closure	%	96	96	86	82

TABLE 3-5 (CONCLUDED)

CH_4 FEED + CH_4 QUENCH

Test No. Exp. Run	18 11-2	19 11-3	20 11-4	21 11-5
H Closure %	103	100	90	87
Y_1 % (C in C_2H_2)/ (C in feed)	61	50	48	56
Y_2 % (C in C_2H_2 + C_2H_4)/ (C in feed + quench)	46	41	33	32
SER_1 (kW-hr/lb C_2H_2)	4.45	4.10	4.41	3.98
SER_2 (kW-hr/lb C_2H_2 + C_2H_4)	4.32	3.91	4.22	3.85

TABLE 3-6

CH_4 FEED + C_2H_6 QUENCH
(NORMAL ANODE)

Test No.		22	23	24	25	26	27
Exp. Run		15-2	15-3	15-5	15-4	15-6	15-7
Pressure	mm Hg	93	100	200	215	300	300
Power Input	kW	81.0	82.5	97.5	100.5	108.0	99.0
Feed Gas	Type	CH_4	CH_4	CH_4	CH_4	CH_4	CH_4
	SCFM	18.7	18.7	18.7	18.7	18.7	18.7
	10^{-3} lb/s	12.9	12.9	12.9	12.9	12.9	12.9
Quench Gas	Type	C_2H_6	C_2H_6	C_2H_6	C_2H_6	C_2H_6	C_2H_6
	SCFM	5.04	7.92	5.04	7.92	5.04	7.92
	10^{-3} lb/s	6.49	10.21	6.49	10.21	6.49	10.21
Process Gas							
Ar	%	1.08	0.99	0.91	0.85	0.87	0.84
	SCFM	0.38	0.38	0.38	0.38	0.38	0.38
Total Flow	SCFM	35.2	38.4	41.8	44.7	43.7	45.2
C_2H_2	%	14.50	13.70	15.83	15.41	15.35	14.37
	SCFM	5.10	5.26	6.62	6.89	6.71	6.50
	10^{-3} lb/s	5.70	5.88	7.40	7.70	7.50	7.27
CH_4	%	17.46	15.50	10.72	8.53	7.87	7.70
	SCFM	6.15	5.95	4.48	3.81	3.44	3.48
	10^{-3} lb/s	4.24	4.11	3.09	2.63	2.38	2.40
C_2H_4	%	1.04	0.78	2.63	1.75	4.12	3.00
	SCFM	0.37	0.30	1.10	0.78	1.80	1.36
	10^{-3} lb/s	0.45	0.36	1.33	0.95	2.18	1.65
C_2H_6	%	11.27	17.38	8.84	15.55	6.47	13.46
	SCFM	3.97	6.67	3.69	6.95	2.82	6.09
	10^{-3} lb/s	5.11	8.61	4.78	8.97	3.65	7.87
H_2	%	53.91	50.95	59.68	56.59	63.68	59.30
	SCFM	18.97	19.56	24.94	25.32	27.83	26.80
	10^{-3} lb/s	1.64	1.69	2.16	2.20	2.42	2.32
N_2	%	0.74	0.71	1.38	1.32	1.64	1.34
Carbon Closure	%	89	89	97	97	93	92

TABLE 3-6 (CONCLUDED)

CH_4 FEED + C_2H_6 QUENCH
(NORMAL ANODE)

Test No.	22	23	24	25	26	27
Exp. Run	15-2	15-3	15-5	15-4	15-6	15-7
H Closure %	94	95	101	101	98	98
Y_1 % (C in C_2H_2)/(C in feed)	56	58	73	76	74	72
Y_2 % (C in C_2H_2 + C_2H_4)/(C in feed + quench)	39	33	55	46	61	47
SER_1 (kW-hr/lb C_2H_2)	3.95	3.90	3.66	3.63	4.00	3.78
SER_2 (kW-hr/lb C_2H_2 + C_2H_4)	3.66	3.67	3.10	3.23	3.10	3.08

TABLE 3-7

CH_4 FEED + C_2H_6 QUENCH
(SHORT ANODE)

Test No.		28	29	30	31	32	33
Exp. Run		18-2	18-3	18-5	18-4	18-6	18-7
Pressure	mm Hg	92	100	205	210	330	315
Power Input	kW	81.0	82.5	96.0	99.0	108.0	91.5
Feed Gas	Type	CH_4	CH_4	CH_4	CH_4	CH_4	CH_4
	SCFM	18.7	18.7	18.7	18.7	18.7	18.7
	10^{-3} lb/s	12.9	12.9	12.9	12.9	12.9	12.9
Quench Gas	Type	C_2H_6	C_2H_6	C_2H_6	C_2H_6	C_2H_6	C_2H_6
	SCFM	5.04	7.92	5.04	7.92	5.04	7.92
	10^{-3} lb/s	6.49	10.21	6.49	10.21	6.49	10.21
Process Gas							
Ar	%	1.05	0.97	0.89	0.84	0.84	0.82
	SCFM	0.38	0.38	0.38	0.38	0.38	0.38
Total Flow	SCFM	36.2	39.2	42.7	45.2	45.2	46.3
C_2H_2	%	14.37	13.45	15.56	15.04	14.99	13.25
	SCFM	5.20	5.27	6.64	6.80	6.77	6.13
	10^{-3} lb/s	5.81	5.89	7.43	7.61	7.57	6.86
CH_4	%	18.23	16.47	12.59	10.79	9.61	11.41
	SCFM	6.60	6.46	5.38	4.88	4.10	5.28
	10^{-3} lb/s	4.56	4.46	3.72	3.37	2.83	3.65
C_2H_4	%	2.76	2.17	4.27	3.45	5.51	4.88
	SCFM	1.00	0.85	1.82	1.56	2.35	2.26
	10^{-3} lb/s	1.21	1.03	2.21	1.89	2.85	2.74
C_2H_6	%	7.90	14.95	4.91	11.38	2.40	10.22
	SCFM	2.86	5.86	2.10	5.14	1.03	4.73
	10^{-3} lb/s	3.69	7.56	2.70	6.63	1.33	6.11
H_2	%	54.97	51.34	61.39	56.86	66.40	58.94
	SCFM	19.90	20.12	26.21	25.70	28.55	27.29
	10^{-3} lb/s	1.73	1.75	2.28	2.23	2.45	2.37
N_2	%	0.72	0.65	0.39	1.64	0.25	0.74
Carbon Closure	%	88	90	94	94	87	93

TABLE 3-7 (CONCLUDED)

CH_4 FEED + C_2H_6 QUENCH
(SHORT ANODE)

Test No.	28	29	30	31	32	33
Exp. Run	18-2	18-3	18-5	18-4	18-6	18-7
H Closure %	91	93	98	96	90	97
Y_1 % (C in C_2H_2)/(C in feed)	57	58	73	75	74	67
Y_2 % (C in C_2H_2 + C_2H_4)/(C in feed + quench)	44	36	61	50	65	50
SER_1 (kW-hr/lb C_2H_2)	3.87	3.89	3.59	3.61	3.96	3.71
SER_2 (kW-hr/lb C_2H_2 + C_2H_4)	3.21	3.31	2.77	2.89	2.88	2.65

in the process (carbon closures of less than 100 percent indicate sooting). The hydrogen closure gives an indication of the experimental errors involved (~ ±10 percent).

3.2 EFFECT OF FLOWRATE OF FEED GAS

Table 3-2 shows a set of experiments conducted to determine the effect of the mass flowrate of the feed. The feed gas was CH_4 and the flowrate was varied from 10 - 22 SCFM. The quench (H_2) was held constant at 32 SCFM. The pressure was kept relatively constant at 100-130 mm Hg. The results show that with H_2 as quench, C_2H_4 formation is very small and, since no carbon enters with the quench, values of the critical parameters based on C_2H_2 alone are almost the same as those based on C_2H_2 and C_2H_4. Figure 3-1 shows these parameters as a function of the feed rate.

The results show that for feed rates between 14 and 22 SCFM, the SER values are independent of the feed rate and are about 3.8 to 4 kW-hr/lb, as both the input power and the C_2H_2 production rate increase. The yield is also quite insensitive to the feed rate and is in the range of 65-75 percent. However, the concentration of acetylene in the product gas shows a sharp increase with increase in feed rate and then approaches a constant value at around 18 to 19 SCFM (based on SER_1, and Y_1 and C_1). For H_2 quench rate of 32 SCFM, the optimum feed rate is around 18 to 19 SCFM. To study the effect of the flowrate of the quench, the feed rate was therefore maintained at 18.7 SCFM.

Figure 3-1 also shows the theoretical minimum SER (based on Figure 1-1) for the range of CH_4 flowrates. In the experiments, the value of kW/(lb/sec of CH_4) varied between 1.1×10^4 (at low flowrate) and 6.7×10^3 (at high flowrate). The experiments show the same trend as the model, with SER values ~ 30 percent above the theoretical minimums.

At the high flowrate, the residence time of the gas between the arc and the quench injection point was estimated to be ~ 2-4 ms. From the results of Ref. 1, we would expect little sooting in this time scale (in agreement with the present data).

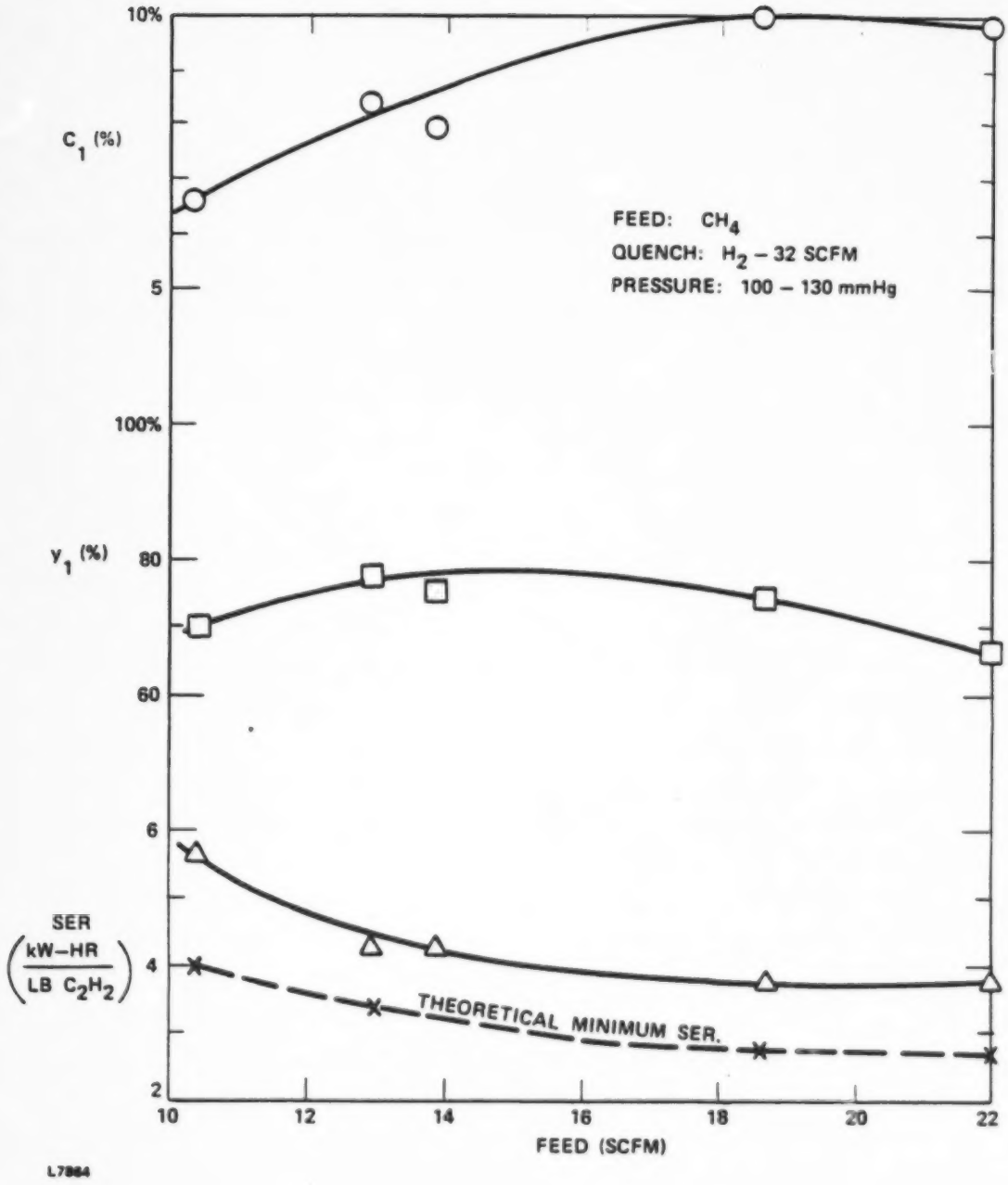


Figure 3-1 Effect of Flowrate of Feed Gas

3.3 EFFECT OF FLOWRATE OF QUENCH

The first four data sets shown in Table 3-3 were taken to determine the effect of the H_2 quench flowrate. The last two data sets are made at higher pressure which is discussed in Section 3.7. Figure 3-2 shows the data in a graphical form. Again, above a quench flowrate of about 15 SCFM, the SER and yield are quite insensitive to the quench rate. The concentration of acetylene in the product gases decreases with increase in the quench flowrate. This is expected since the H_2 rate quench (beyond a limit) does not have any effect on the conversion, and the addition of more H_2 only adds to the total volume of the product gas, thereby decreasing the concentration of acetylene. The optimum flowrate of hydrogen quench is about 15 SCFM for a feed rate of 18.7 SCFM. The SER is in the range of 3.6 to 4.0 kW-hr/lb of acetylene.

Figure 3-3 shows the results obtained with CH_4 and C_2H_6 quenches. The results show that the yields are poorer with CH_4 quench as compared to H_2 and C_2H_6 quenches. The SERs and acetylene concentration do not vary substantially for the three quenches used. It should be noted that in this section, only the parameters based on acetylene and feed alone are being compared. The parameters based on acetylene plus ethylene and feed plus quench is discussed in subsection 3.5.

3.4 EFFECT OF COMPOSITION OF FEED GAS

An 80:20 molar mixture of CH_4 and H_2 was used as feed to determine the effect of the composition of the feed gas. The results are shown in Table 3-4 and Figure 3-4. The dashed lines in Figure 3-4 are for CH_4 feed only and are reproduced here from Figure 3-1, for easy comparison.

The SERs for the mixed feed are slightly higher than those for CH_4 feed alone. It may be argued that part of the energy input goes towards heating up of hydrogen in the mixed gas feed and therefore increases the SER. The C_2H_2 yields are lower for the mixed feed than for CH_4 feed probably because of lower conversion. The concentration of acetylene in the product gases is lower for the mixed feed than for CH_4 feed.

This is a result of both lower yields and excess H_2. Hence, it appears that feed mixture of CH_4 and H_2 has no apparent advantage over CH_4 alone under the conditions investigated.

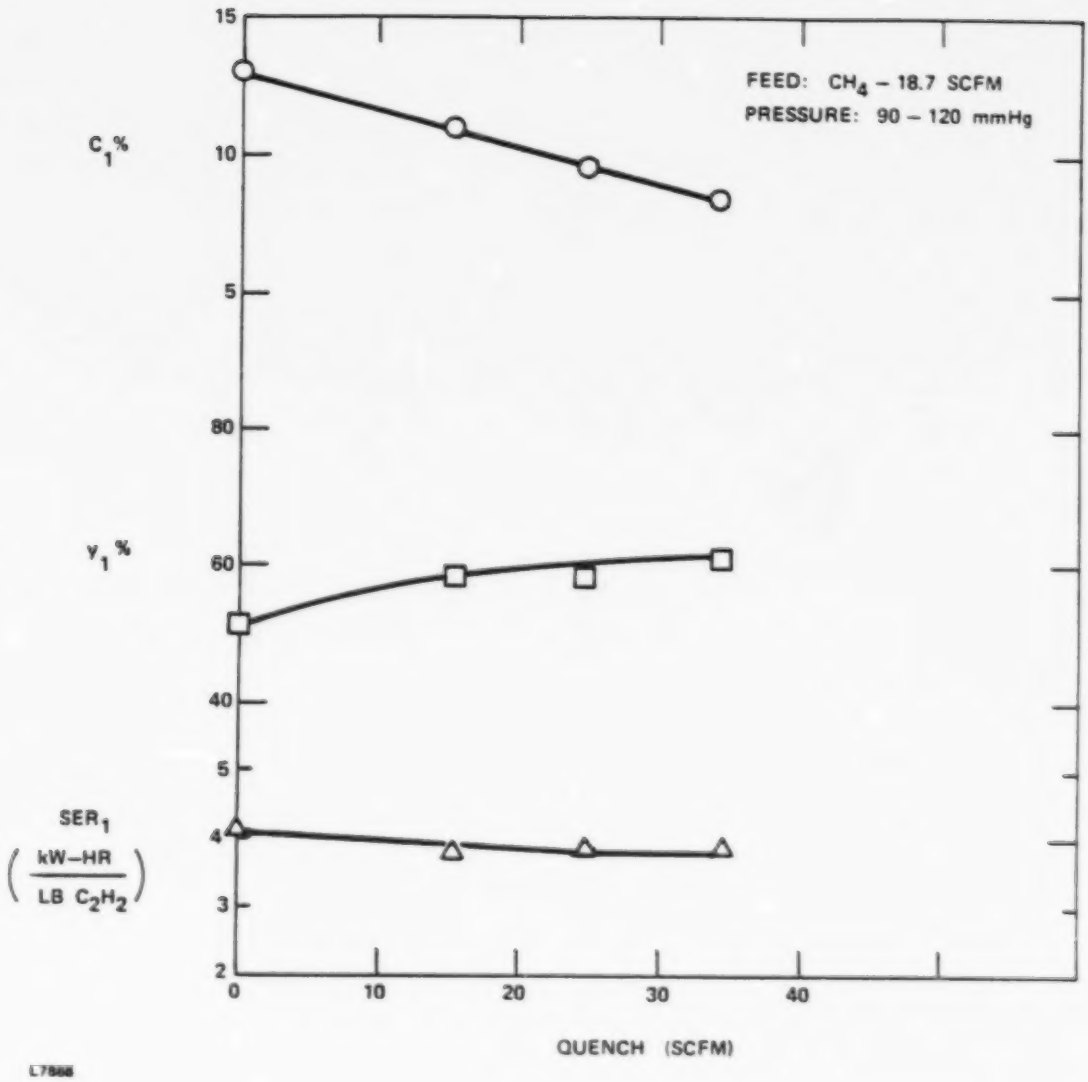


Figure 3-2 Effect of Flowrate of H_2 Quench

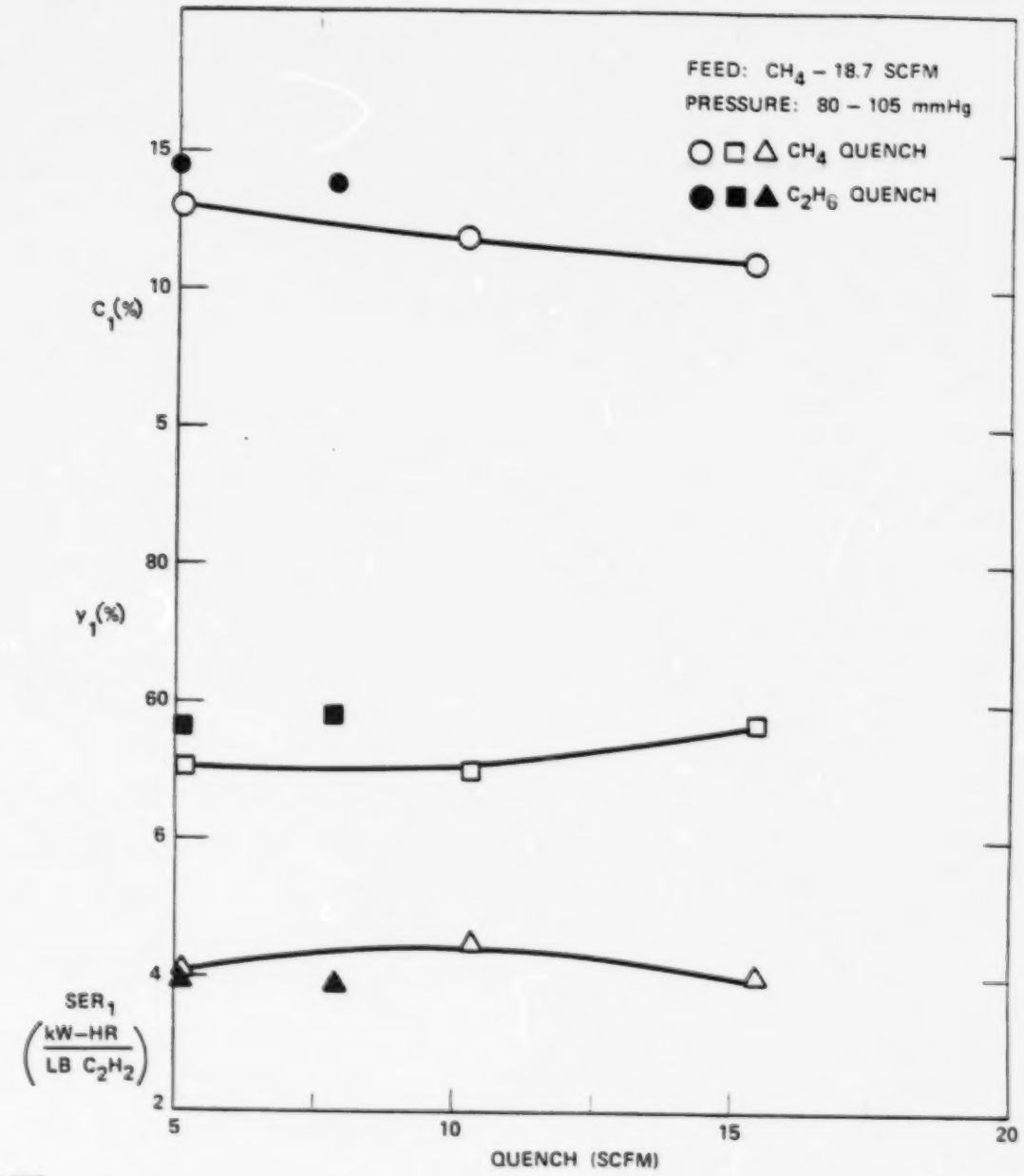


Figure 3-3 Effect of Flowrate of CH_4 and C_2H_6 Quenches

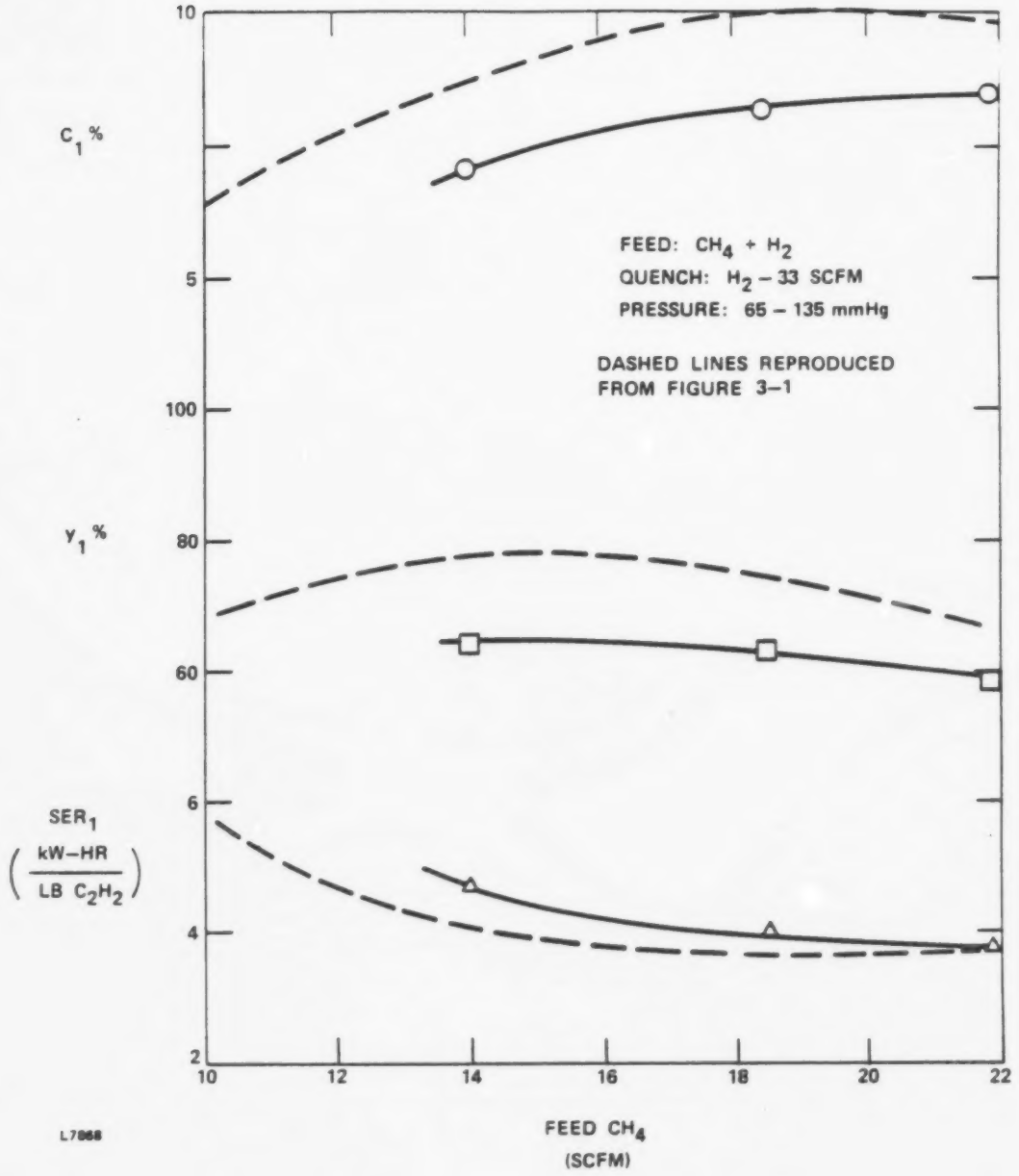


Figure 3-4 Effect of Composition of Feed Gas

3.5 EFFECT OF NATURE OF QUENCH

To ascertain the effect of the nature of quench, three different types of quenches were used; viz, H_2, CH_4 and C_2H_6. The results are shown in Tables 3-3, 3-5 and 3-6, respectively. The purpose of this study was to determine a suitable quench medium which would give lower SERs and higher product yields.

The results show that CH_4 quench gave poorer yields based on acetylene alone than H_2 and C_2H_6 quenches. This was discussed above in Section 3.3. One other interesting observation is that, whereas both H_2 and CH_4 quenches give very little production of C_2H_4, when C_2H_6 is used as quench, substantial amounts of C_2H_4 are produced. This shows that the quench C_2H_6 does take part in the reactions and therefore its role is physio-chemical in nature. This also makes it essential to consider the composition of the quench in both of the definitions of the three critical parameters under study.

3.6 EFFECT OF INJECTION POINT OF THE QUENCH

Since it is determined that the quench does take part in the reaction, it is logical to assume that the location of the quench would have an effect on the composition of the products. To confirm this, the length of the anode was shortened, thereby allowing the quench to be introduced closer to the arc (product gases are at higher temperatures near the arc).

The C_2H_6 quench was used in these experiments since it is the only quench which is converted in significant amount. The feed (CH_4) rate was kept constant at 18.7 SCFM and two levels of quench rates were employed (5.04 and 7.92 SCFM). The pressure was varied from 75 to 330 mm Hg. Results of both normal and short anodes are shown in tabular form in Tables 3-6 and 3-7 and in graphical form in Figures 3-5 to 3-10.

The results show that the location of the quench has no effect on the parameters based on acetylene and feed alone, indicating that C_2H_6 quench does not add to the C_2H_2 production. However, the data show that when C_2H_6 is introduced at a higher point, greater amounts of C_2H_4 are formed.

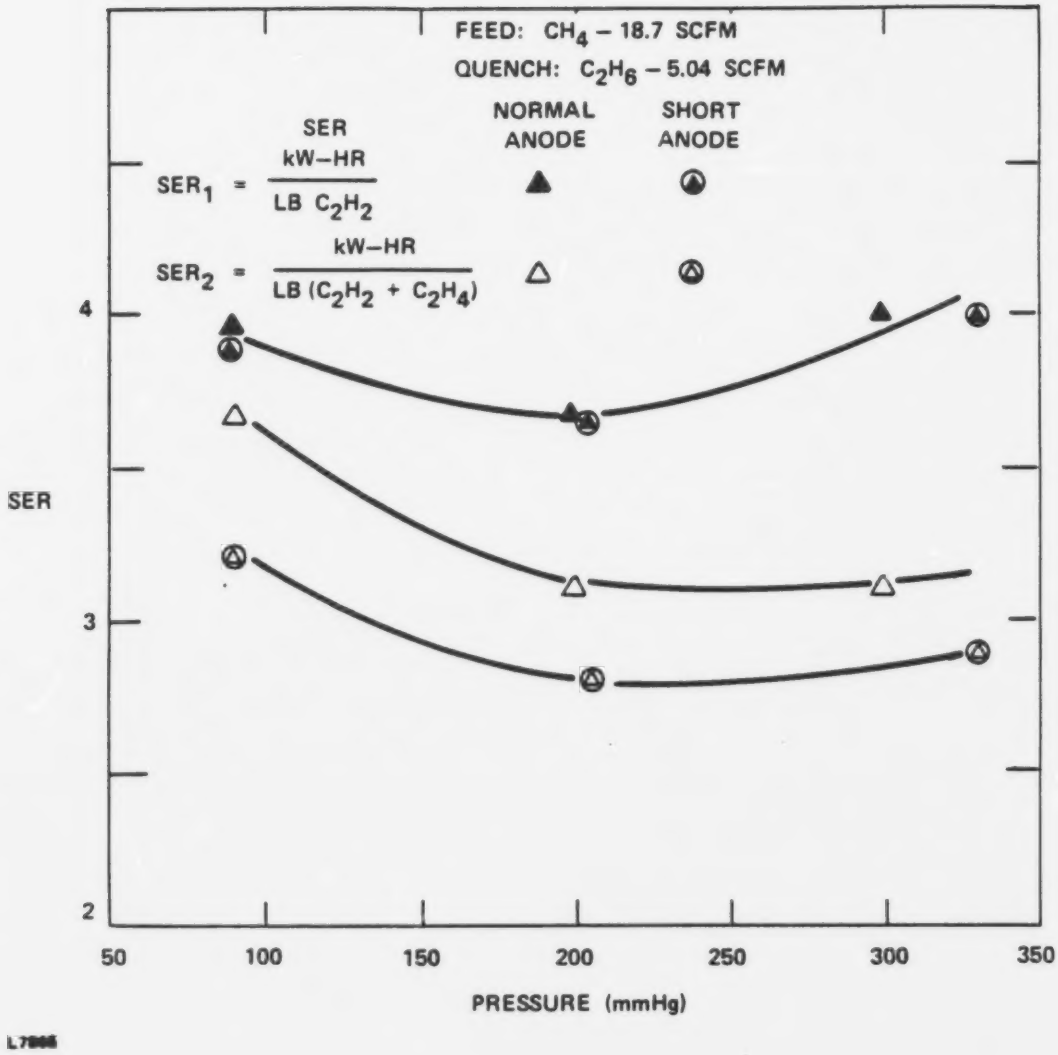


Figure 3-5 Effect of Injection Point of Quench on SER (Lower Quench Flow)

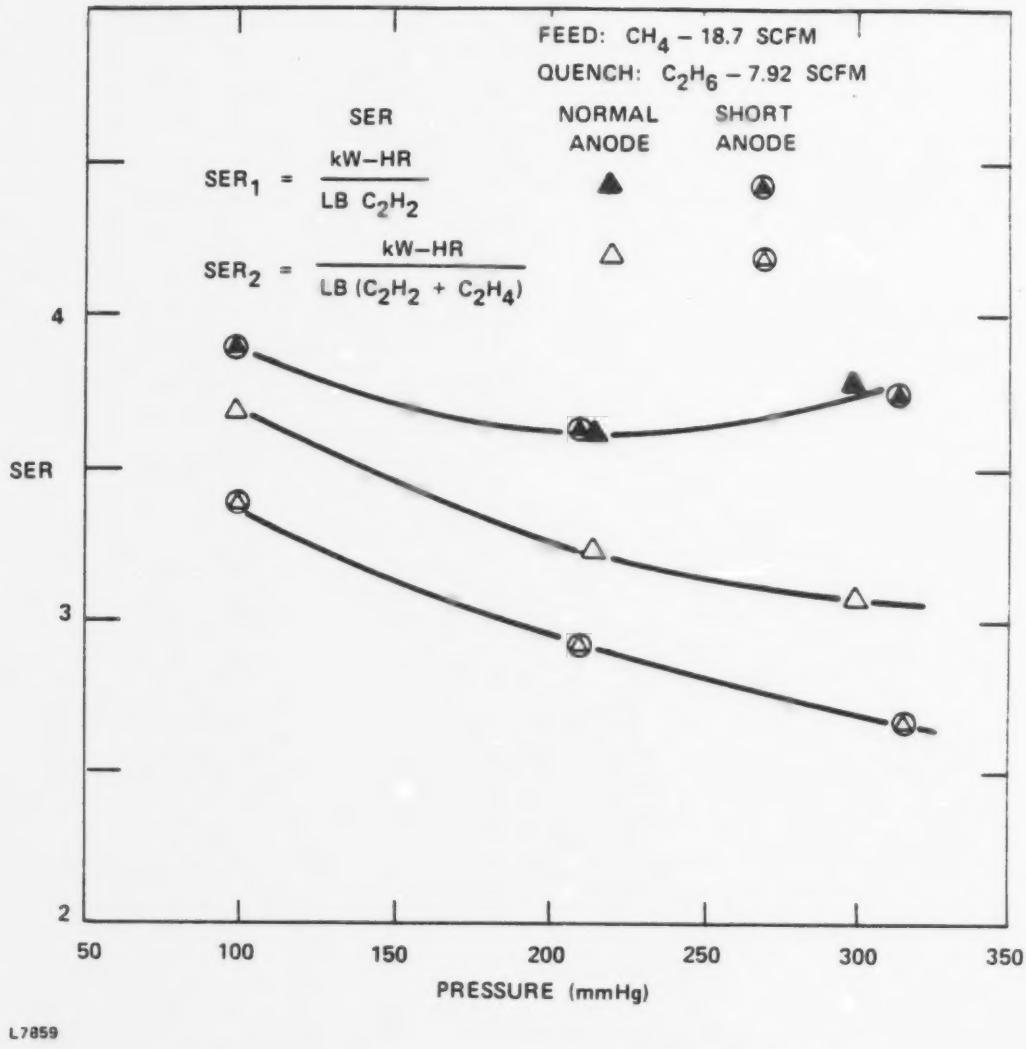


Figure 3-6 Effect of Injection Point of Quench on SER (Higher Quench Flow)

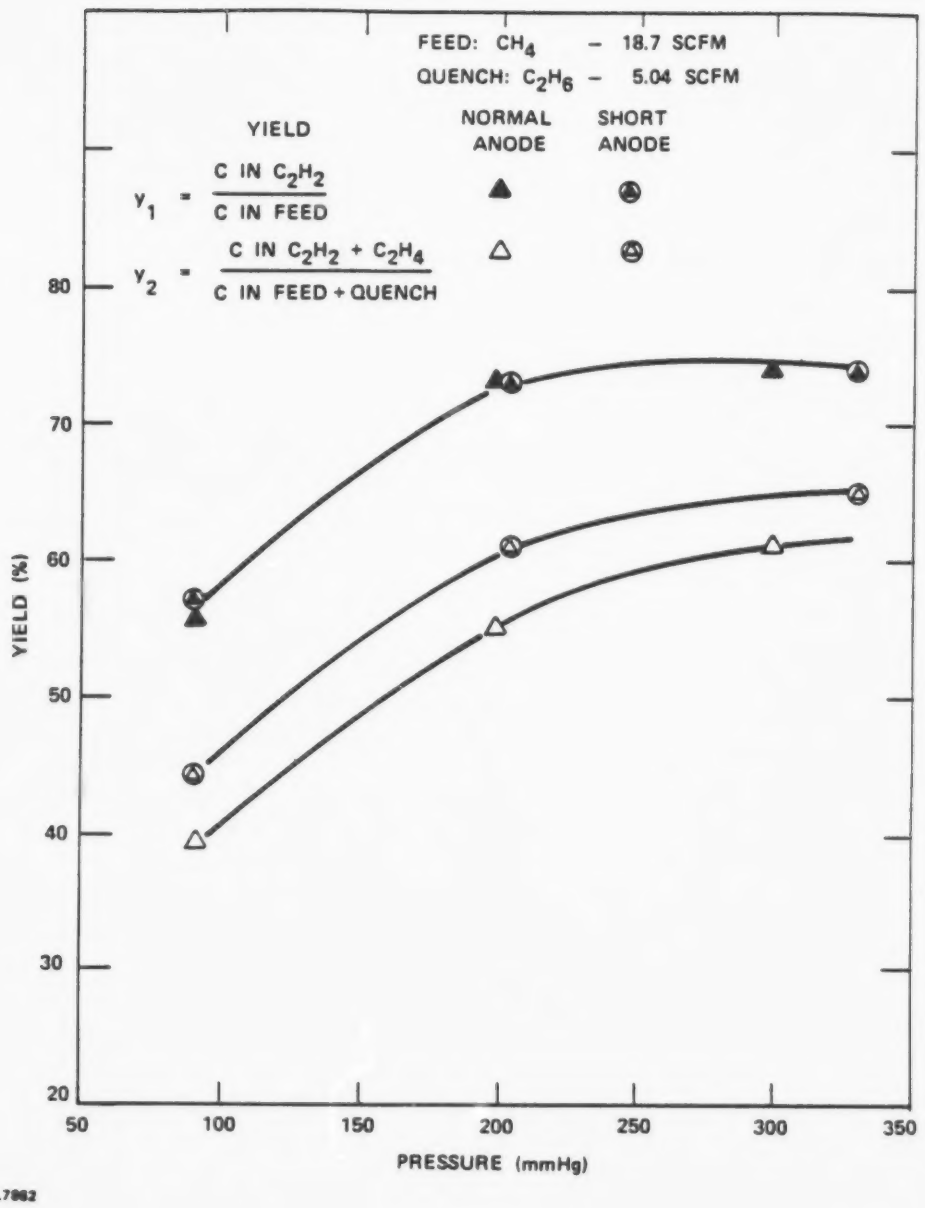


Figure 3-7 Effect of Injection Point of Quench on Yield of Acetylene and Ethylene (Lower Quench Flow)

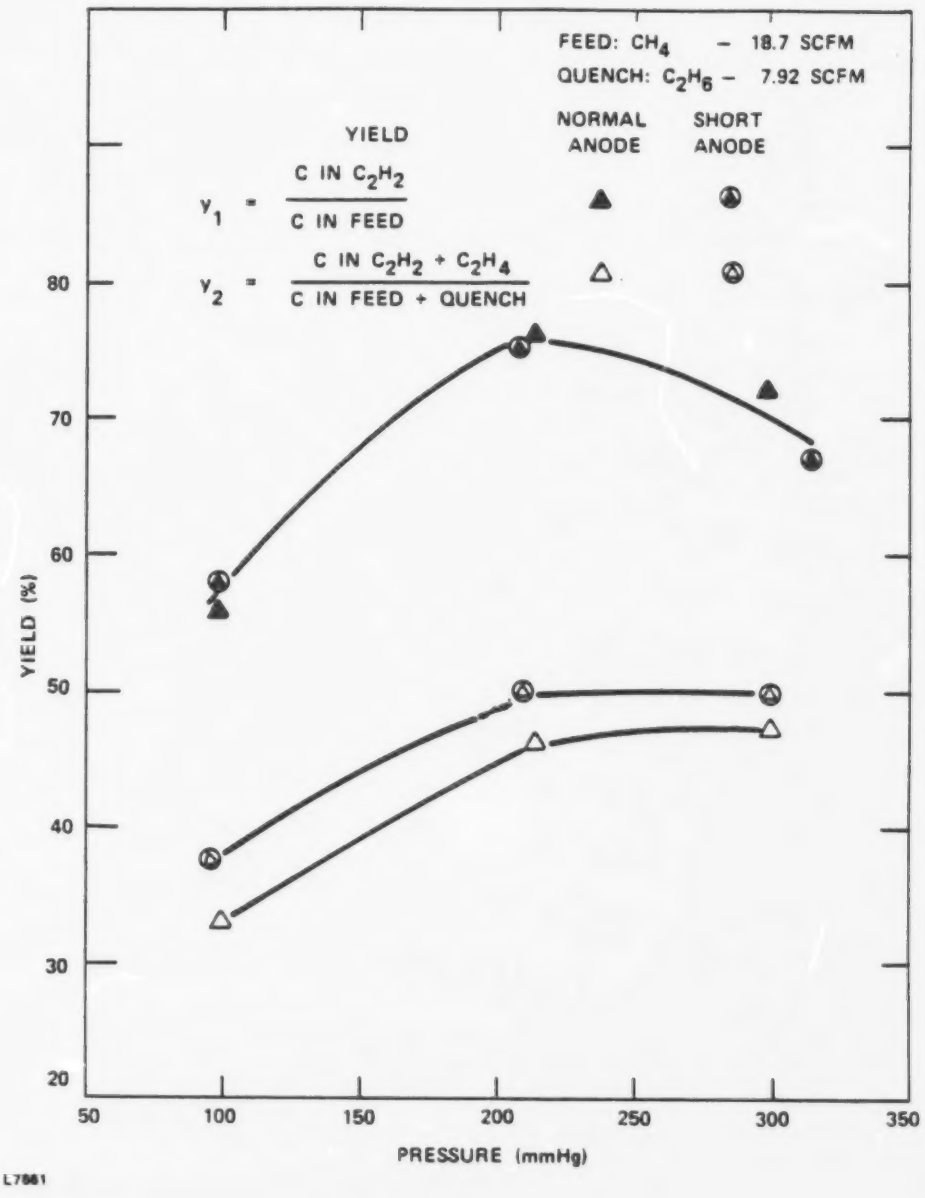


Figure 3-8 Effect of Injection Point of Quench on Yield of Acetylene and Ethylene (Higher Quench Flow)

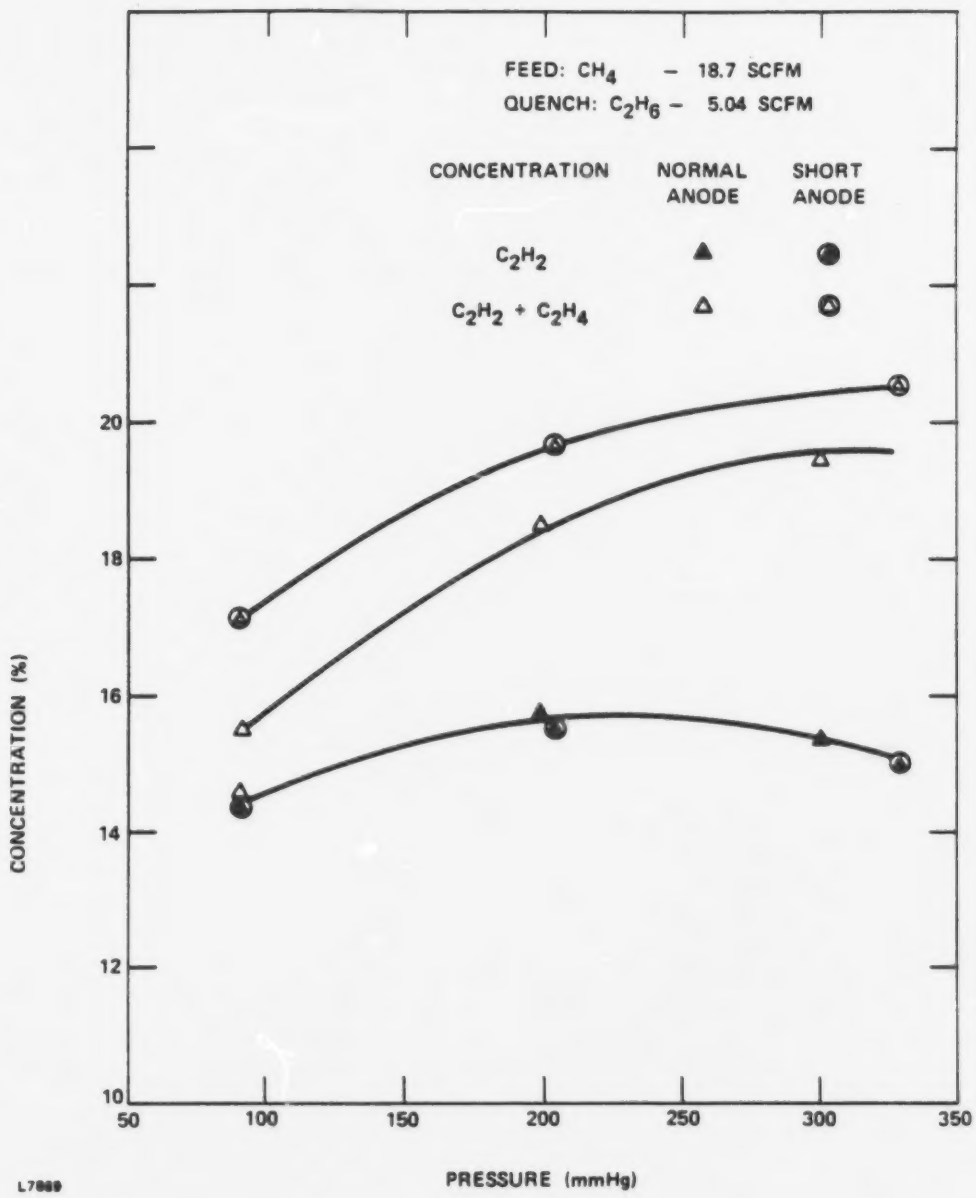


Figure 3-9 Effect of Injection Point of Quench on Concentration of Acetylene and Ethylene (Lower Quench Flow)

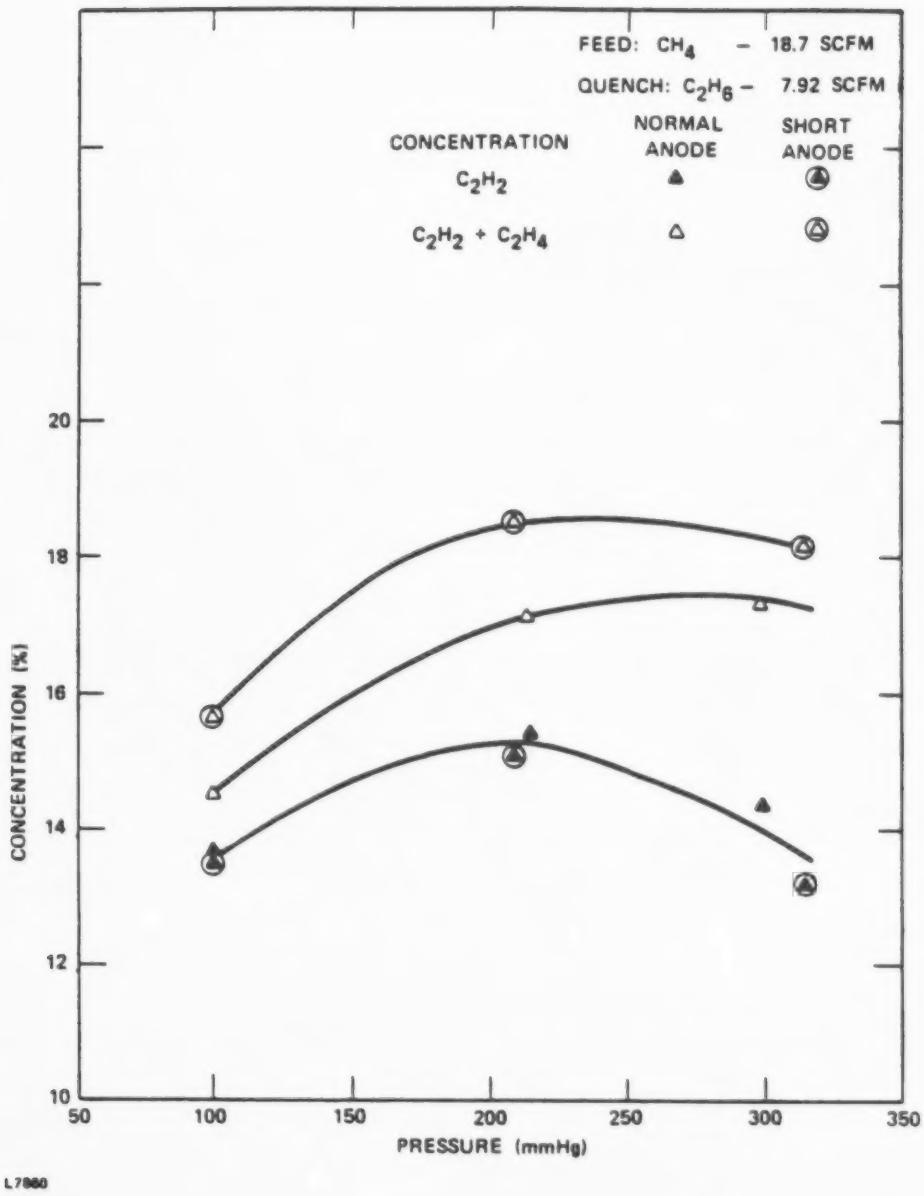


Figure 3-10 Effect of Injection Point of Quench on Concentration of Acetylene and Ethylene (Higher Quench Flow)

In these cases, the short anode gives lower SERs, higher yields and higher concentrations than the normal anode when acetylene and ethylene are taken as the product. This is a desirable result and is of direct consequence in the design of arc-acetylene processes.

3.7 EFFECT OF PRESSURE

The effect of pressure was determined by holding the feed and quench rates constant and varying the system pressure. Figure 3-11 shows the results with H_2 quench. The SER changes marginally with pressure. The yield and concentrations increase initially with increase in pressure, but tend to level off or decrease at higher pressures. Similar conclusions can also be drawn from Figures 3-5 to 3-10, where C_2H_6 quench is used. A pressure of 200 mm Hg does seem to be an optimum value, giving low SERs and high yields and concentrations. This is particularly true for the C_2H_6 quench.

3.8 CONCLUSION

An experimental study has been conducted to explore the effect of process variables on three critical parameters of the arc-acetylene process, viz, yield (Y) of acetylene and ethylene, the specific energy requirement (SER) to produce 1 lb of acetylene and ethylene and the concentration (C) of acetylene and ethylene in the product gases. The process variables studied were the feed gas composition and flowrate, the nature, flowrate and injection point of the quench and the system pressure.

The following conclusions can be drawn from this study:

1. For a given pressure and quench flowrate, the SER, Y and C values obtained depend on the feed rate of natural gas, and an optimum value can be determined to give low values of SER and high values of Y and C. The same is true when quench rates are varied at fixed feed rate and system pressure.
2. Addition of H_2 to the natural gas feedstock does not have any apparent advantage over CH_4 feed alone.
3. CH_4 quench gives poorer yields than H_2 or C_2H_6 quenches.
4. The role of the quench is physicochemical in nature.

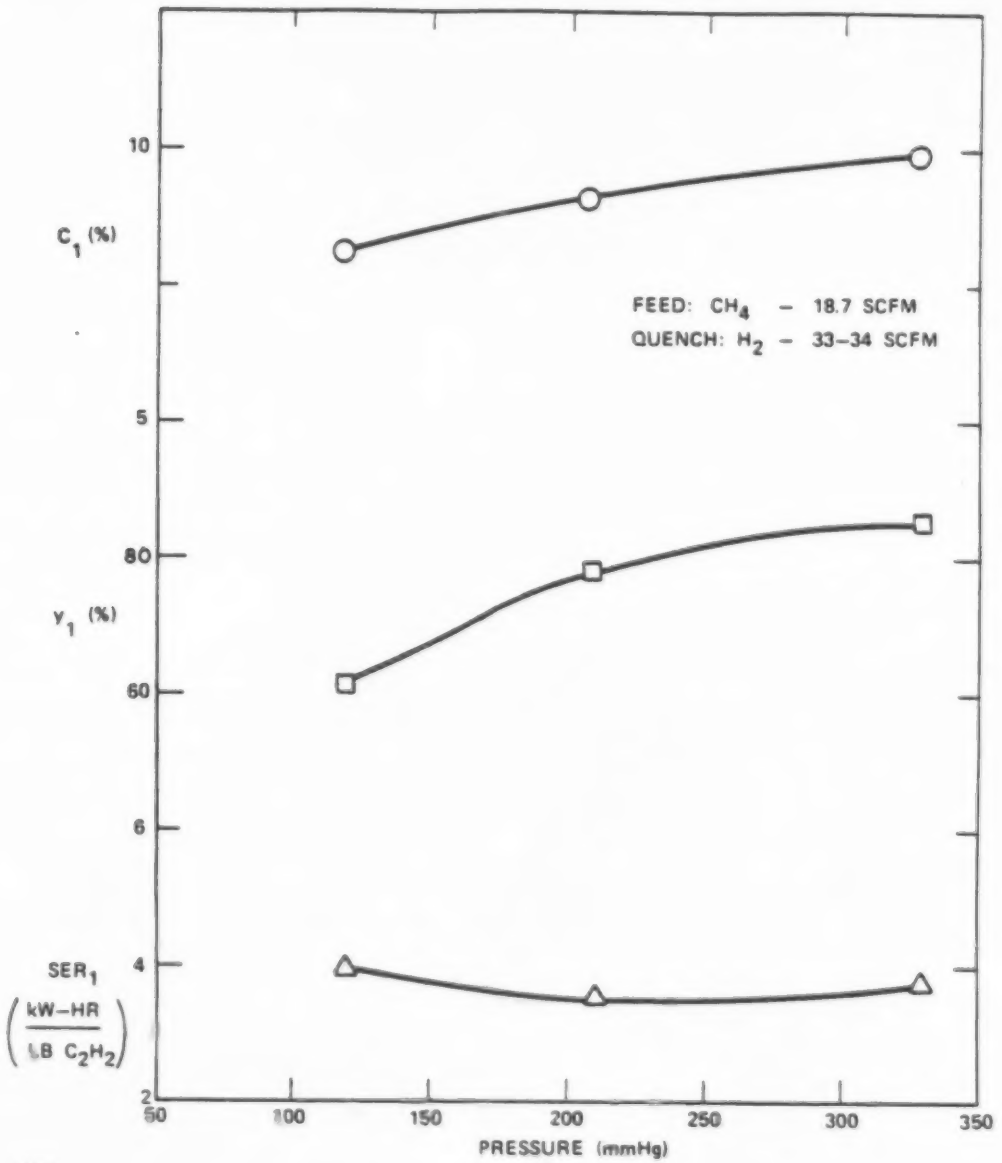


Figure 3-11 Effect of Pressure

5. C_2H_6 quench gives substantial production of C_2H_4 (a valuable product).
6. The location of the quench relative to the arc is an important parameter in the design of the reactor, particularly when using a hydrocarbon quench.
7. Acetylene yield and conentration increased with increasing pressure over the range of 125 to 330 mm Hg. SER values remained relatively constant over the same range.

4.0 PROCESS PERFORMANCE WITH SCALED-UP REACTORS

The tests in this program have been carried out in a subscale reactor (≃ 100 kW). Of greater interest for commercial application would be modules of sizes larger than 1 MW.

From the general trend of the carbon closures, the amount of carbon converted to soot is small (~ 5%). However, a significant amount of CH_4 remains unreacted in the 100 kw reactor, probably because of heat transfer to the water-cooled walls by the gas near the walls. For a large reactor, much less unreacted methane would be expected (1-2 percent as opposed to 15-20 percent). With H_2 quench, then, we project (based on acetylene yield above) at 0.5-1 atm operating pressure:

$SER_1 \cong 3.5$
$Yield_1 > 90\%$
Concentration of $C_2H_2 > 10\%$

For C_2H_6 quench, we would again expect reduced amounts of unreacted CH_4 and C_2H_6; we project (based on C_2H_2 and C_2H_4 yield), at 0.5-1 atm:

$SER_2 \cong 2.5$
$Yield_2 > 90\%$
Concentration of C_2H_2 and $C_2H_4 > 20\%$

From comparison of the arc-discharge data obtained on CH_4 feed with previous data[2] on other gases, a scaling calculation for the reactor size can be performed.

The size of the reactor is mainly a factor of power level (voltage and current), reactor pressure, the type of gas passed through the arc, and the massflow per unit area. The key scaling parameter for a given reactor pressure and reactor environment is the voltage gradient (volts/inch). Figure 4-1

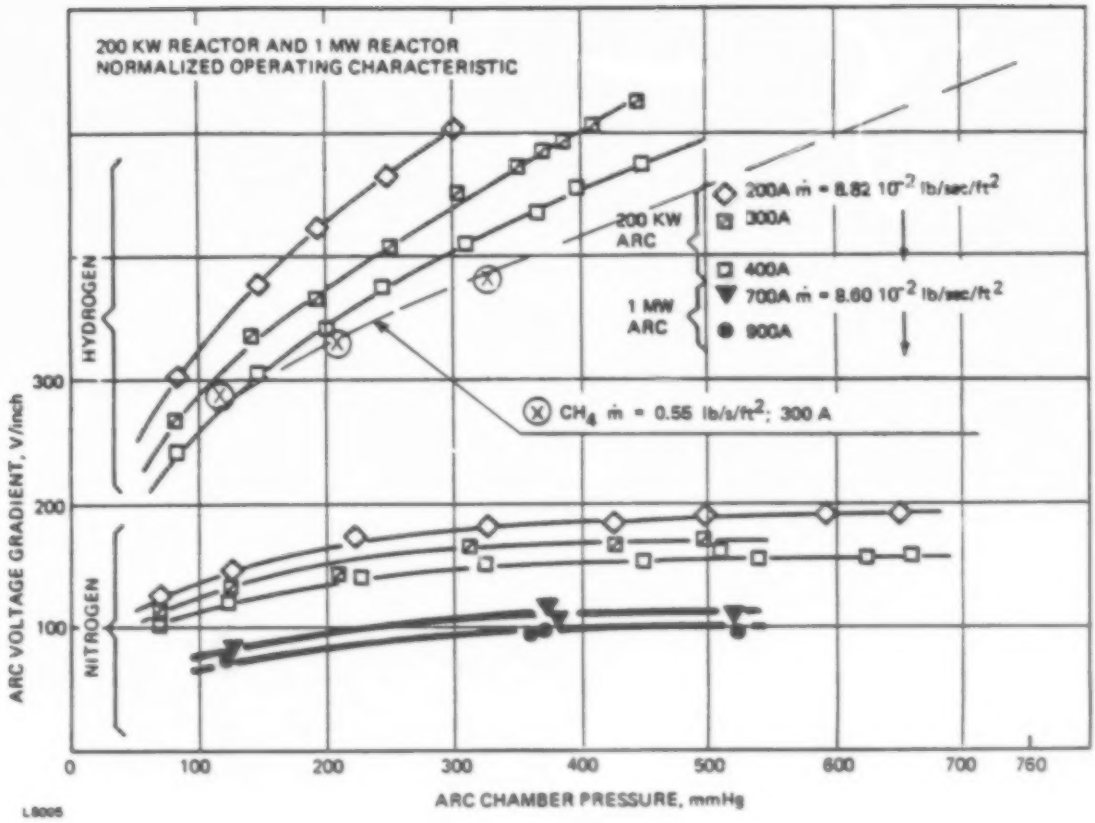


Figure 4-1 Normalized Operating Characteristics

shows the dependency of the voltage gradient on the reactor pressure for N_2, H_2 and CH_4. Because of the negative arc characteristic, the voltage decreases with increasing arc current as shown in Figure 4-2. Taking these factors into consideration, the following reactor sizes result.

ESTIMATED REACTOR SIZES FOR CH_4

Power Input	MW	5	8	5	8	8
Arc Voltage	V	5000	8000	2500	4000	8000
Arc Current	A	1000	1000	2000	2000	1000
Reactor Pressure	atm	0.5	0.5	0.5	0.5	1.0
Reactor Diameter	ft	4.2	6.7	2.8	4.5	4.0

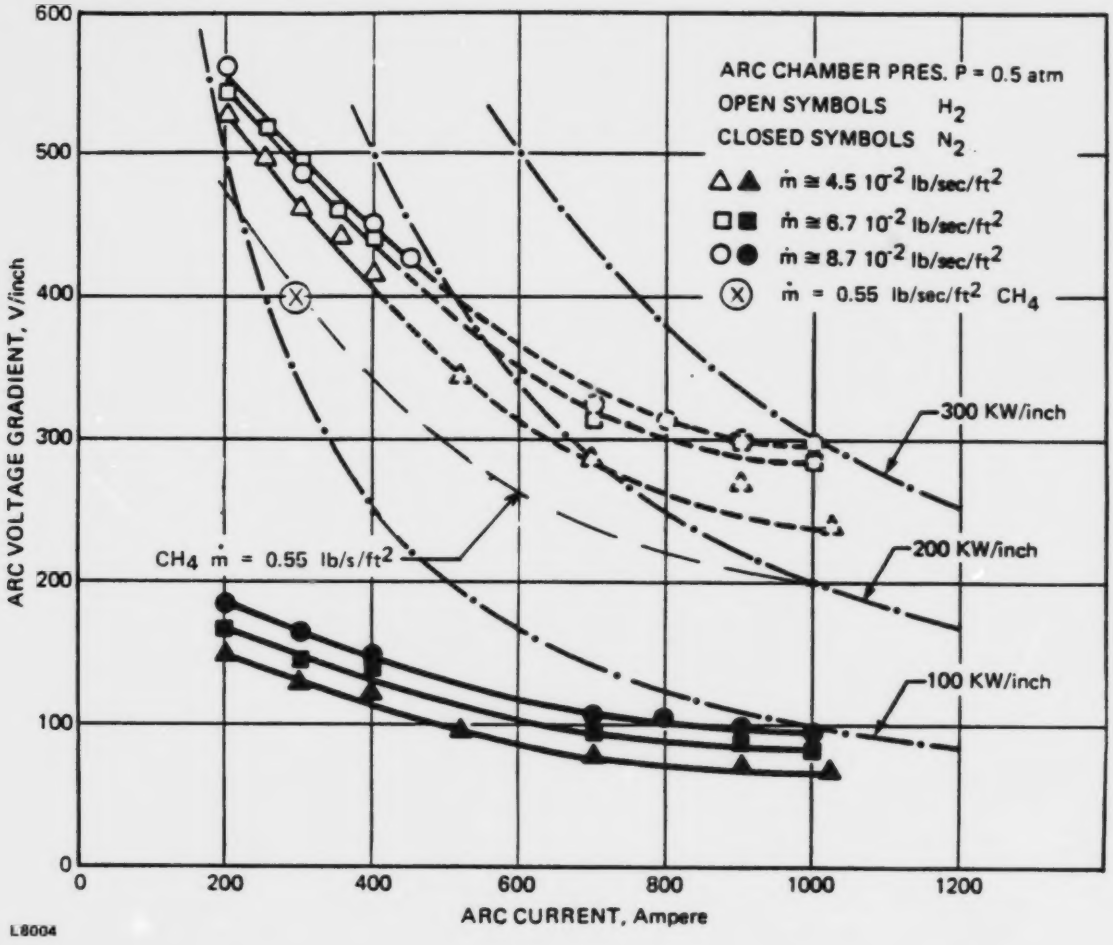


Figure 4-2 Expanded Normalized Operating Characteristics

5.0 REFERENCE

1. Kim, C.S., Gannon, R.E., and Ubhayakar, S., "Design and Modeling of an Arc Coal Acetylene Reactor," AIChe Meeting, Boston, August 1979.

2. "Avco Arc-Coal Acetylene Process Development Program," Final Technical Progress Report, October 1980.

APPENDIX C

MATERIAL BALANCE FOR A LIQUID FUEL PLANT VIA THE ELECTRIC-ARC ACETYLENE REACTOR PROCESS USING ETHANE, HYDROGEN OR LPG AS QUENCH

Appendix C-1. Material Balance for a Liquid Fuel Plant via the Electric-Arc Acetylene Reactor Process using Ethane Quench

Plant Capacity: 12 500 bbl/d Gasoline Product

STREAM	1	2	3	4	5	6	7	8
STREAM IDENTIFICATION	Natural Gas	Recycle Gas	Total Feed	Quench	Reactor Effluent	Dry Carbon	Wet Carbon	Gas to Oil Scrubber
COMPONENTS								
N_2	1785	1559	3344		3344			3344
CO_2	497		497					
CH_4	51715	2463	54178		4107			4107
C_2H_6	2253	4164	6417	35920	4066			4066
C_3H_8/C_4H_{10}	189	1	190		738			738
H_2		659	659		14252			14252
CO		941	941		1574			1574
C_2H_2		3982	3982		41866			41866
C_2H_4		739	739		31687			31687
C_3H_6		16	16		863			863
C_3/C_4 ACETYLENES & DIENES		3603	3603		4265			4265
BUTENES		5	5		165			165
C_5H_6/C_6H_6					836	115	289	432
H_2O						93	576	
CARBON					2403	2100	288	15
HIGHER HYDROCARBONS					320			320
HCN					5			5
GASOLINE								
FLOWRATE, kg/hr	56439	18132	74571	35920	110491	2308	1153	107699

Appendix C-1: Material Balance for Ethane Quench (Cont'd)

STREAM	9	10	11	12	13	14	15	16
STREAM IDENTIFICATION	Residual Oil	Benzene	Gas to MeOH Scrubber	Stripping Gas	Gas to Hydrogenation Unit	Recycle Gas to Reactor	Olefin Rich Feed	Mobil Reactor Outlet
COMPONENTS								
N_2			3344	1554	3339	1559	3339	3339
CO_2								
CH_4			4107	2443	4087	2463	4087	4087
C_2H_6			4066	4156	4058	4164	6809	6952
C_3H_8/C_4H_{10}			730		737	1	3781	10388
H_2			14252	642	14235	659	9831	9831
CO			1574	938	1571	941	1571	1571
C_2H_2			41866		37884	3982	757	
C_2H_4			31916		31177	739	66960	
C_3H_6			1053		1037	16	1293	626
C_3/C_4 ACETYLENES & DIENES			4265		662	3603	13	
BUTENES			426		421	5	767	1904
C_5H_6/C_6H_6	174	258						
H_2O			454					
CARBON	15							
HIGHER HYDROCARBONS	320							
HCN								
GASOLINE								60510
FLOWRATE, kg/hr	509	258	108061	9733	99208	18132	99208	99208

Appendix C-1: Material Balance for Ethane Quench (Cont'd)

STREAM	17	18	19	20	21	22	23	24
STREAM IDENTIFICATION	Gasoline	LPG By-product	Off Gas	Hydrogen By-product	Recycle Gas	Fuel Gas	Recycle Gas to Reactor	LPG Recycle
COMPONENTS								
N_2			3339	740	2599	1045	1554	
CO_2								
CH_4			4087		4087	1644	2443	
C_2H_6			6952		6952	2796	4156	
C_3H_8/C_4H_{10}		10388						
H_2			9831	8758	1073	431	642	
CO			1571	2	1569	631	938	
C_2H_2								
C_2H_4								
C_3H_6		626						
C_3/C_4 ACETYLENES & DIENES								
BUTENES		1904						
C_5H_6/C_6H_6								
H_2O								
CARBON								
HIGHER HYDROCARBONS								
HCN								
GASOLINE	60510							
FLOWRATE, kg/hr	60510*	12918	25780	9500	16280	6547	9733	0

* Benzene produced 258 kg/h (Stream 10) is blended with gasoline (Stream 17) to give 60510 + 258 = 60768 kg/h of final gasoline product.

Appendix C-2. Material Balance for a Liquid Fuel Plant via the Electric-Arc Acetylene Reactor Process using Hydrogen Quench

Plant Capacity: 12 500 bbl/d Gasoline Product

STREAM	1	2	3	4	5	6	7	8
STREAM IDENTIFICATION	Natural Gas	Recycle Gas	Total Feed	Quench	Reactor Effluent	Dry Carbon	Wet Carbon	Gas to Oil Scrubber
COMPONENTS								
N_2	3022	2478	5500	1188	5500			5500
CO_2	842		842					
CH_4	87412	3323	90735		4556			4556
C_2H_6	3693	2802	6495		638			638
C_3H_8/C_4H_{10}	322	1	323		906			906
H_2		2266	2266	14062	34965			34965
CO		2867	2867	2	3940			3940
C_2H_2		6577	6577		67961			67961
C_2H_4		173	173		7038			7038
C_3H_6		14	14		602			602
C_3/C_4 ACETYLENES & DIENES		1196	1196		1490			1490
BUTENES		7	7		119			119
C_5H_6/C_6H_6					1041	149	372	520
H_2O						119	743	
CARBON					3098	2708	372	18
HIGHER HYDROCARBONS					387			387
HCN					6			6
GASOLINE								
FLOWRATE, kg/hr	95291	21704	116995	15252	132247	2976	1487	128646

Appendix C-2: Material Balance for Hydrogen Quench (Cont'd)

STREAM	9	10	11	12	13	14	15	16
STREAM IDENTIFICATION	Residual Oil	Benzene	Gas to MeOH Scrubber	Stripping Gas	Gas to Hydrogenation Unit	Recycle Gas to Reactor	Olefin Rich Feed	Mobil Reactor Outlet
COMPONENTS								
N_2			5500	2470	5492	2478	5492	5492
CO_2								
CH_4			4556	3302	4535	3323	4535	4535
C_2H_6			638	2801	637	2802	3702	3846
C_3H_8/C_4H_{10}			906		905	1	5783	12377
H_2			34965	2237	34936	2266	27922	27922
CO			3940	2863	3936	2867	3936	3936
C_2H_2			67961		61384	6577	1227	
C_2H_4			7408		7235	173	66515	
C_3H_6			909		895	14	997	484
C_3/C_4 ACETYLENES & DIENES			1490		294	1196	6	
BUTENES			542		535	7	669	1803
C_5H_6/C_6H_6	210	310						
H_2O			1018					
CARBON	18							
HIGHER HYDROCARBONS	387							
HCN								
GASOLINE								60389
FLOWRATE, kg/hr	615	310	129833	13673	120784	21704	120784	120784

Appendix C-2: Material Balance for Hydrogen Quench (Cont'd)

STREAM	17	18	19	20	21	22	23	24
STREAM IDENTIFICATION	Gasoline	LPG By-Product	Off Gas	Hydrogen By-product	Recycle Gas	Fuel Gas	Recycle Gas to Reactor	LPG Recycle
COMPONENTS								
N_2			5492	912	3392	922	2470	
CO_2								
CH_4			4535		4535	1233	3302	
C_2H_6			3846		3846	1045	2801	
C_3H_8/C_4H_{10}		12377						
H_2			27922	10788	3072	835	2237	
CO			3936	2	3932	1069	2863	
C_2H_2								
C_2H_4								
C_3H_6		484						
C_3/C_4 ACETYLENES & DIENES								
BUTENES		1803						
C_5H_6/C_6H_6								
H_2O								
CARBON								
HIGHER HYDROCARBONS								
HCN								
GASOLINE	60389							
FLOWRATE, kg/hr	60389*	14664	45731	11702	18777	5104	13673	0

* Benzene produced 310 kg/h (Stream 10) is blended with gasoline (Stream 17) to give 60389 + 310 = 60699 kg/h of gasoline product.

Appendix C-3. Material Balance for a Liquid Fuel Plant via the Electric-Arc Acetylene Reactor Process using LPG Quench

Plant Capacity: 12 500 bbl/d Gasoline Product

STREAM	1	2	3	4	5	6	7	8
STREAM IDENTIFICATION	Natural Gas	Recycle Gas	Total Feed	Quench	Reactor Effluent	Dry Carbon	Wet Carbon	Gas to Oil Scrubber
COMPONENTS								
N_2	2326	1979	4305		4305			4305
CO_2	648		648					
CH_4	67510	5949	73459		10759			10759
C_2H_6	2874	2747	5621		1994			1994
C_3H_8/C_4H_{10}	247	3	250	30706	3071			3071
H_2		596	596		15118			15118
CO		1016	1016		1842			1842
C_2H_2		5296	5296		55129			55129
C_2H_4		402	402		16957			16957
C_3H_6		71	71		4326			4326
C_3/C_4 ACETYLENES & DIENES		4570	4570		5887			5887
BUTENES		10	10		531			531
C_5H_6/C_6H_6					1581	146	366	1069
H_2O						117	730	
CARBON					3045	2661	366	18
HIGHER HYDROCARBONS					2400			2400
HCN					5			5
GASOLINE								
FLOWRATE, kg/hr	73605	22639	96244	30706*	126950	2924	1462	123411

* Make-Up LPG required = LPG used as quench-LPG recycle
= 30706 (Stream 4) - 18577 (Stream 18) = 12129 kg/h

Appendix C-3: Material Balance for LPG Quench (Cont'd)

STREAM	9	10	11	12	13	14	15	16
STREAM IDENTIFICATION	Residual Oil	Benzene By-product	Gas to MeOH Scrubber	Stripping Gas	Gas to Hydrogenation Unit	Recycle Gas to Reactor	Olefin Rich Feed	Mobil Reactor Outlet
COMPONENTS								
N_2			4305	1972	4298	1979	4298	4298
CO_2								
CH_4			10759	5898	10708	5949	10708	10708
C_2H_6			1994	2743	1990	2747	4831	4975
C_3H_8/C_4H_{10}			3071		3068	3	6942	13530
H_2			15118	583	15105	596	9601	9601
CO			1842	1013	1838	1016	1838	1838
C_2H_2			55129		49833	5296	997	
C_2H_4			17242		16840	402	64634	
C_3H_6			4563		4492	71	4939	2395
C_3/C_4 ACETYLENES & DIENES			5887		1317	4570	27	
BUTENES			856		846	10	1520	2652
C_5H_6/C_6H_6	430	639						
H_2O	18		567					
CARBON								
HIGHER HYDROCARBONS	2400							
HCN								
GASOLINE								60338
FLOWRATE, kg/hr	2848	639	121333	12209	110335	22639	110335	110335

Appendix C-3: Material Balance for LPG Quench (Cont'd)

STREAM	17	18	19	20	21	22	23	24
STREAM IDENTIFICATION	Gasoline	LPG By-product	Off Gas	Hydrogen By-product	Recycle Gas	Fuel Gas	Recycle Gas to Reactor	LPG Recycle
COMPONENTS								
N_2			4298	722	3576	1604	1972	
CO_2								
CH_4			10708		10708	4810	5898	
C_2H_6			4975		4975	2232	2743	
C_3H_8/C_4H_{10}								13530
H_2			9601	8545	1056	473	583	
CO			1838	1	1837	824	1013	
C_2H_2								
C_2H_4								2395
C_3H_6								
C_3/C_4 ACETYLENES & DIENES								
BUTENES								2652
C_5H_6/C_6H_6								
H_2O								
CARBON								
HIGHER HYDROCARBONS								
HCN								
GASOLINE	60338							
FLOWRATE, kg/hr	60338*	0	31420	9268	22152	9943	12209	18577

* Benzene produced 639 kg/h (Stream 10) is blended with gasoline (Stream 17) to give 60338 + 639 = 60977 kg/h of gasoline product.

APPENDIX D

SOME ECONOMIC AND FINANCIAL ASSUMPTIONS AND DATA

Appendix D-1 Canada/USA Material Price Differential Factor

Reference Location: Gulf Coast (USA)

Plant Location : Quebec (Canada)

	Relative Price*	Material** Distribution %	Price Differential
Concrete Mix	1.37	30	0.411
Standard Structure			
Wide Flanges	1.27	7.5	0.095
I-Beams	1.21	7.5	0.095
Piping			
Iron	1.2	36.0	0.432
Copper	1.3	9.0	0.117
Cables/Wires	1.10	10.0	0.11
		100.0	1.26

Sources:

* Engineering News Record, June 4, 1984; January 30, 1986

** Based on SNC in-house data on various petrochemical projects.

Appendix D-2 Productivity Adjustment Factor

A review of labor productivity based on petrochemical projects indicates that a multiple of 1.05 be applied for conversion of U.S. Gulf Coast labor to equivalent Canadian labor.

For adjustment to the Quebec region, climatic factors must also be considered. Therefore, an allowance of 12 days per year has been provided for adverse working conditions during winter.

$$\text{Allowance} = \frac{12 \text{ days} \times 3 \text{ winters}}{36 \text{ months} * 22 \text{ days/month}} = 0.047$$

Thus, the overall labor adjustment factor = 1.05 * 1.047 = 1.10

Appendix D-3 Machinery, Equipment and Plant Indices

Year	Marshall and Stevens Equipment Cost Index *	Chemical Engineering Plant Index *	Chemical and Petrochemical Plant Index **
1974	398.4	165.4	49.7
1975	444.3	182.4	58.8
1976	472.1	192.1	64.0
1977	505.4	204.1	69.0
1978	545.3	218.8	74.4
1979	599.4	238.7	81.8
1980	659.6	261.2	90.2
1981	721.3	297.0	100.0
1982	745.6	314.0	110.2
1983	760.8	316.9	115.5
1984	780.4	322.7	118.5
1985	792.0 (4th Q.)	325.1 (Dec. 85)	122.7 (3rd Q.)

Sources:

* Chemical Engineering, "Economic Indicators", February 17, 1986.

** Statistics Canada, "Construction Price Statistics", Catalogue 62-007, Third Quarter, 1985.

Appendix D-4 Experimental Factors for Capacity Adjustment of Costs of Equipment Items

Equipment Item	Factor
Air Cooler	0.8
Cooling Towers	0.60
Exchangers	
Conventional	0.65
Reboilers	0.50
Filters	0.60 - 0.65
Furnaces	0.80 - 0.85
Generators/Electrical Support	0.75
Motors	0.90 - 1.00
Pressurized Vessels	
Columns and Reactors	0.65 - 0.70
Tanks	0.60 - 0.65
Horizontal Storage Tanks	0.65
Vertical Storage Tanks	0.70
Pump	
Centrifugal	0.40 - 0.50
Reciprocating	0.60 - 0.70
Refrigeration	0.70
Steam Generation	0.80

Source:

Chauvel et al, Institut Français du Pétrole, "Manual of Economic Analysis of Chemical Process", McGraw Hill Book Company, N.Y., 1981.

Appendix D-5 Typical Manpower Distribution and Average Salary Scale

	% of Total Manpower
Operating Labour (OL)	34
Operation Supervisors (20% of OL)	7
Maintenance Labour (ML)	42
Maintenance Supervision (20% of ML)	8.5
Plant Management and Administrative Support	8.5

Source: Rogers, K.A., and Hill, R.F., ESCOE, DOE Report No. FE-2468-51, July 1979

APPENDIX E-1 FINANCIAL ANALYSES (ETHANE QUENCH)

- in constant dollars with no escalation assuming 100% equity financing
- in current dollars with 5% escalation per annum assuming 40% debt financing at 12% interest rate per year

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	208683	231870	231870	231870	231870	231870	231870
HYDROGEN		0	0	0	61569	68410	68410	68410	68410	68410	68410
LPG		0	0	0	31806	35340	35340	35340	35340	35340	35340
TOTAL		0	0	0	302058	335620	335620	335620	335620	335620	335620
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	64656	71840	71840	71840	71840	71840	71840
ELECTRICITY		0	0	0	65232	72480	72480	72480	72480	72480	72480
QUENCH(ETHANE)		0	0	0	76815	85350	85350	85350	85350	85350	85350
CATALYST & CHEMICALS		0	0	0	15011	16160	16160	16160	16160	16160	16160
MAKE-UP WATER		0	0	0	358	385	385	385	385	385	385
ROYALTIES (10 YEARS)		0	0	0	2160	2400	2400	2400	2400	2400	2400
LABOUR SUP. & OP. SUPPLY		0	0	0	2610	2610	2610	2610	2610	2610	2610
MAINTEN. (INCL. LABOUR)		0	0	0	15040	15040	15040	15040	15040	15040	15040
PROP. TAXES & INSURANCE		0	0	0	7520	7520	7520	7520	7520	7520	7520
OVERHEAD/ADMINISTRATION		0	0	0	6180	6180	6180	6180	6180	6180	6180
SUBTOTAL		0	0	0	255582	279965	279965	279965	279965	279965	279965
CAPITAL COST ALLOWANCE		0	0	0	22989	22989	22989	22989	22989	19343	19343
SUBTOTAL		0	0	0	22989	22989	22989	22989	22989	19343	19343
TOTAL		0	0	0	278571	302954	302954	302954	302954	299308	299308
GROSS INCOME		0	0	0	23487	32666	32666	32666	32666	36312	36312
TAXABLE INCOME		0	0	0	23487	32666	32666	32666	32666	36312	36312
INCOME TAX		0	0	0	8690	12086	12086	12086	12086	13435	13435
NET INCOME		0	0	0	14797	20580	20580	20580	20580	22877	22877
RETURN ON SALES-%		0.00	0.00	0.00	4.90	6.13	6.13	6.13	6.13	6.82	6.82
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	3.64	5.07	5.07	5.07	5.07	5.63	5.63

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		231870	231870	231870	231870	231870	231870	231870	231870	231870	231870
HYDROGEN		68410	68410	68410	68410	68410	68410	68410	68410	68410	68410
LPG		35340	35340	35340	35340	35340	35340	35340	35340	35340	35340
TOTAL		335620	335620	335620	335620	335620	335620	335620	335620	335620	335620
ANNUAL EXPENSES											
NATURAL GAS		71840	71840	71840	71840	71840	71840	71840	71840	71840	71840
ELECTRICITY		72480	72480	72480	72480	72480	72480	72480	72480	72480	72480
QUENCH(ETHANE)		85350	85350	85350	85350	85350	85350	85350	85350	85350	85350
CATALYST & CHEMICALS		16160	16160	16160	16160	16160	16160	16160	16160	16160	16160
MAKE-UP WATER		385	385	385	385	385	385	385	385	385	385
ROYALTIES (10 YEARS)		2400	2400	2400	0	0	0	0	0	0	0
LABOUR SUP. & OP. SUPPLY		2610	2610	2610	2610	2610	2610	2610	2610	2610	2610
MAINTEN. (INCL. LABOUR)		15040	15040	15040	15040	15040	15040	15040	15040	15040	15040
PROP. TAXES & INSURANCE		7520	7520	7520	7520	7520	7520	7520	7520	7520	7520
OVERHEAD/ADMINISTRATION		6180	6180	6180	6180	6180	6180	6180	6180	6180	6180
SUBTOTAL		279965	279965	279965	277565	277565	277565	277565	277565	277565	277565
CAPITAL COST ALLOWANCE		19343	19343	19343	19343	19343	19343	19343	19343	19343	19343
SUBTOTAL		19343	19343	19343	19343	19343	19343	19343	19343	19343	19343
TOTAL		299308	299308	299308	296908	296908	296908	296908	296908	296908	296908
GROSS INCOME		36312	36312	36312	38712	38712	38712	38712	38712	38712	38712
TAXABLE INCOME		36312	36312	36312	38712	38712	38712	38712	38712	38712	38712
INCOME TAX		13435	13435	13435	14323	14323	14323	14323	14323	14323	14323
NET INCOME		22877	22877	22877	24389	24389	24389	24389	24389	24389	24389
RETURN ON SALES-%		6.82	6.82	6.82	7.27	7.27	7.27	7.27	7.27	7.27	7.27
RETURN ON FIXED ASSETS-%		5.63	5.63	5.63	6.00	6.00	6.00	6.00	6.00	6.00	6.00

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		231870	231870	231870
HYDROGEN		68410	68410	68410
LPG		35340	35340	35340
TOTAL		335620	335620	335620
ANNUAL EXPENSES				
NATURAL GAS		71840	71840	71840
ELECTRICITY		72480	72480	72480
QUENCH(ETHANE)		85350	85350	85350
CATALYST & CHEMICALS		16160	16160	16160
MAKE-UP WATER		385	385	385
ROYALTIES (10 YEARS)		0	0	0
LABOUR SUP. & OP. SUPPLY		2610	2610	2610
MAINTEN. (INCL. LABOUR)		15040	15040	15040
PROP. TAXES & INSURANCE		7520	7520	7520
OVERHEAD/ADMINISTRATION		6180	6180	6180
SUBTOTAL		277565	277565	277565
CAPITAL COST ALLOWANCE		19343	19343	19343
SUBTOTAL		19343	19343	19343
TOTAL		296908	296908	296908
GROSS INCOME		38712	38712	38712
TAXABLE INCOME		38712	38712	38712
INCOME TAX		14323	14323	14323
NET INCOME		24389	24389	24389
RETURN ON SALES-%		7.27	7.27	7.27
RETURN ON FIXED ASSETS-%		6.00	6.00	6.00

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		100022	211707	144217	0	0	0	0	0	0	0
NET INCOME		0	0	0	14797	20580	20580	20580	20580	22877	22877
CAPITAL COST ALLOWANCE		0	0	0	22989	22989	22989	22989	22989	19343	19343
TOTAL		100022	211707	144217	37786	43569	43569	43569	43569	42220	42220
APPLICATIONS OF FUNDS											
LAND		1200	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		110264	240576	150360	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		-13232	-28869	-18043	-15036	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-19580	-19580	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	1400	0	0	0	0	0	0	0
START-UP COSTS		0	0	15040	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	15040	0	0	0	0	0	0	0
TOTAL		100022	211707	144217	-34616	0	0	0	0	0	0
GENERATED CASH		0	0	0	72402	43569	43569	43569	43569	42220	42220
EQUITY CASH FLOW		-100022	-211707	-144217	72402	43569	43569	43569	43569	42220	42220
ACCUMULATED CASH FLOW		-100022	-311729	-455946	-383544	-339976	-296407	-252839	-209270	-167050	-124831

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
NET INCOME		22877	22877	22877	24389	24389	24389	24389	24389	24389	24389
CAPITAL COST ALLOWANCE		19343	19343	19343	19343	19343	19343	19343	19343	19343	19343
TOTAL		42220	42220	42220	43732	43732	43732	43732	43732	43732	43732
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
TOTAL		0	0	0	0	0	0	0	0	0	0
GENERATED CASH		42220	42220	42220	43732	43732	43732	43732	43732	43732	43732
EQUITY CASH FLOW		42220	42220	42220	43732	43732	43732	43732	43732	43732	43732
ACCUMULATED CASH FLOW		-82611	-40392	1828	45559	89291	133023	176754	220486	264217	307949

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
NET INCOME		24389	24389	24389
CAPITAL COST ALLOWANCE		19343	19343	19343
TOTAL		43732	43732	43732
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
TOTAL		0	0	0
GENERATED CASH		43732	43732	43732
EQUITY CASH FLOW		43732	43732	43732
ACCUMULATED CASH FLOW		351680	395412	439144

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	10.18	7.35
PAYBACK PERIOD-YEARS	7.74	9.96
TERMINAL WORTH	16240	58546

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	266338	310728	326264	342578	359706	377692	396576
HYDROGEN		0	0	0	78579	91676	96260	101073	106126	111433	117004
LPG		0	0	0	40593	47359	49727	52213	54824	57565	60443
TOTAL		0	0	0	385511	449763	472251	495863	520657	546689	574024
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	82519	96272	101086	106140	111447	117020	122871
ELECTRICITY		0	0	0	83254	97130	101987	107086	112440	118062	123965
QUENCH(ETHANE)		0	0	0	98038	114377	120096	126101	132406	139026	145977
CATALYST & CHEMICALS		0	0	0	19158	21656	22739	23876	25069	26322	27639
MAKE-UP WATER		0	0	0	457	516	542	569	597	627	658
ROYALTIES (10 YEARS)		0	0	0	2160	2400	2400	2400	2400	2400	2400
LABOUR/SUP. & OP. SUPPLY		0	0	0	3331	3498	3673	3856	4049	4251	4464
MAINTEN.(INCL. LABOUR)		0	0	0	19195	20155	21163	22221	23332	24499	25723
PROP. TAXES & INSURANCE		0	0	0	9598	10078	10581	11110	11666	12249	12862
OVERHEAD/ADMINISTRATION		0	0	0	7887	8282	8696	9131	9587	10067	10570
SUBTOTAL		0	0	0	325598	374364	392962	412490	432994	454524	477130
CAPITAL COST ALLOWANCE		0	0	0	28504	28504	28504	28504	28504	24081	24081
INTEREST EXPENSE-LOAN 1		0	0	0	30921	29159	27186	24976	22500	19728	16622
SUBTOTAL		0	0	0	59425	57663	55690	53479	51004	43789	40694
TOTAL		0	0	0	385023	432027	448651	465969	483998	498313	517824
GROSS INCOME		0	0	0	488	17736	23600	29894	36659	48377	56210
TAXABLE INCOME		0	0	0	488	17736	23600	29894	36659	48377	56210
INCOME TAX		0	0	0	181	6562	8732	11061	13564	17899	20798
NET INCOME		0	0	0	308	11174	14868	18833	23095	30477	35412
RETURN ON SALES-%		0.00	0.00	0.00	0.08	2.48	3.15	3.80	4.44	5.57	6.17
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	0.06	2.21	2.94	3.73	4.57	6.04	7.01

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

P R O F I T A N D L O S S S T A T E M E N T

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		416405	437225	459087	482041	506143	531450	558022	585923	615220	645981
HYDROGEN		122855	128997	135447	142219	149330	156797	164637	172869	181512	190588
LPG		63466	66639	69971	73469	77143	81000	85050	89302	93767	98456
TOTAL		602725	632861	664504	697729	732616	769247	807709	848094	890499	935024
ANNUAL EXPENSES											
NATURAL GAS		129014	135465	142238	149350	156818	164659	172891	181536	190613	200143
ELECTRICITY		130164	136672	143505	150681	158215	166125	174432	183153	192311	201926
QUENCH(ETHANE)		153276	160940	168987	177436	186308	195624	205405	215675	226459	237782
CATALYST & CHEMICALS		29021	30472	31996	33595	35275	37039	38891	40835	42877	45021
MAKE-UP WATER		691	726	762	800	840	882	927	973	1022	1073
ROYALTIES (10 YEARS)		2400	2400	2400	0	0	0	0	0	0	0
LABOUR/SUP. & OP. SUPPLY		4687	4922	5168	5426	5697	5982	6281	6595	6925	7271
MAINTEN.(INCL. LABOUR)		27010	28360	29778	31267	32830	34472	36196	38005	39906	41901
PROP. TAXES & INSURANCE		13505	14180	14889	15634	16415	17236	18098	19003	19953	20950
OVERHEAD/ADMINISTRATION		11098	11653	12236	12848	13490	14165	14873	15617	16397	17217
SUBTOTAL		500867	525790	551959	577037	605889	636184	667993	701392	736462	773285
CAPITAL COST ALLOWANCE		24061	24061	24061	24061	24061	24061	24061	24061	24061	24061
INTEREST EXPENSE-LOAN 1		13144	9249	4886	0	0	0	0	0	0	0
SUBTOTAL		37206	33310	28948	24061	24061	24061	24061	24061	24061	24061
TOTAL		538072	559100	580907	601099	629950	660245	692054	725454	760523	797346
GROSS INCOME		64653	73761	83597	96631	102665	109002	115655	122641	129976	137678
TAXABLE INCOME		64653	73761	83597	96631	102665	109002	115655	122641	129976	137678
INCOME TAX		23922	27292	30931	35753	37986	40331	42792	45377	48091	50941
NET INCOME		40731	46469	52666	60877	64679	68671	72863	77264	81885	86737
RETURN ON SALES-%		6.76	7.34	7.93	8.73	8.83	8.93	9.02	9.11	9.20	9.28
RETURN ON FIXED ASSETS-%		8.07	9.20	10.43	12.06	12.81	13.60	14.43	15.30	16.22	17.18

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		678280	712194	747803
HYDROGEN		200117	210123	220629
LPG		103379	108548	113975
TOTAL		981775	1030864	1082407
ANNUAL EXPENSES				
NATURAL GAS		210151	220658	231691
ELECTRICITY		212023	222624	233755
QUENCH(ETHANE)		249671	262154	275262
CATALYST & CHEMICALS		47272	49636	52118
MAKE-UP WATER		1126	1183	1242
ROYALTIES (10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		7635	8017	8418
MAINTEN.(INCL. LABOUR)		43996	46196	48505
PROP. TAXES & INSURANCE		21998	23098	24253
OVERHEAD/ADMINISTRATION		18076	18982	19931
SUBTOTAL		811949	852547	895174
CAPITAL COST ALLOWANCE		24061	24061	24061
INTEREST EXPENSE-LOAN 1		0	0	0
SUBTOTAL		24061	24061	24061
TOTAL		836011	876608	919235
GROSS INCOME		145765	154256	163172
TAXABLE INCOME		145765	154256	163172
INCOME TAX		53933	57075	60374
NET INCOME		91832	97181	102798
RETURN ON SALES-%		9.35	9.43	9.50
RETURN ON FIXED ASSETS-%		18.19	19.25	20.36

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		66770	147046	96339	0	0	0	0	0	0	0
LONG TERM DEBT	1	45920	109423	102336	0	0	0	0	0	0	0
NET INCOME		0	0	0	308	11174	14868	18833	23095	30477	35412
CAPITAL COST ALLOWANCE		0	0	0	28504	28504	28504	28504	28504	24061	24061
TOTAL		112690	256470	198675	28811	39677	43371	47337	51599	54539	59474
APPLICATIONS OF FUNDS											
LAND		1323	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		121566	278497	182764	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		-14588	-33419	-21931	-19190	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-23800	-24990	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	1702	0	0	0	0	0	0	0
START-UP COSTS		0	0	18281	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	18281	0	0	0	0	0	0	0
CAPITALIZED INTEREST		2599	11392	23379	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	0	0	0	14684	16446	18419	20629	23105	25878	28983
TOTAL		112690	256470	198675	-29496	16446	18419	20629	23105	25878	28983
GENERATED CASH		0	0	0	58307	23232	24952	26708	28494	28661	30491
EQUITY CASH FLOW		-66770	-147046	-96339	58307	23232	24952	26708	28494	28661	30491
ACCUMULATED CASH FLOW		-66770	-213817	-310156	-251848	-228617	-203665	-176957	-148463	-119802	-89311
DEBT COVERAGE RATIO		0.00	0.00	0.00	2.28	1.51	1.55	1.59	1.62	1.63	1.67

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
LONG TERM DEBT	1	0	0	0	0	0	0	0	0	0	0
NET INCOME		40731	46469	52666	60877	64679	68671	72863	77264	81885	86737
CAPITAL COST ALLOWANCE		24061	24061	24061	24061	24061	24061	24061	24061	24061	24061
TOTAL		64793	70531	76728	84939	88741	92732	96924	101325	105946	110798
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
CAPITALIZED INTEREST		0	0	0	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	32461	36356	40719	0	0	0	0	0	0	0
TOTAL		32461	36356	40719	0	0	0	0	0	0	0
GENERATED CASH		32332	34175	36009	84939	88741	92732	96924	101325	105946	110798
EQUITY CASH FLOW		32332	34175	36009	84939	88741	92732	96924	101325	105946	110798
ACCUMULATED CASH FLOW		-56980	-22805	13204	98142	186883	279615	376539	477864	583810	694608
DEBT COVERAGE RATIO		1.71	1.75	1.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

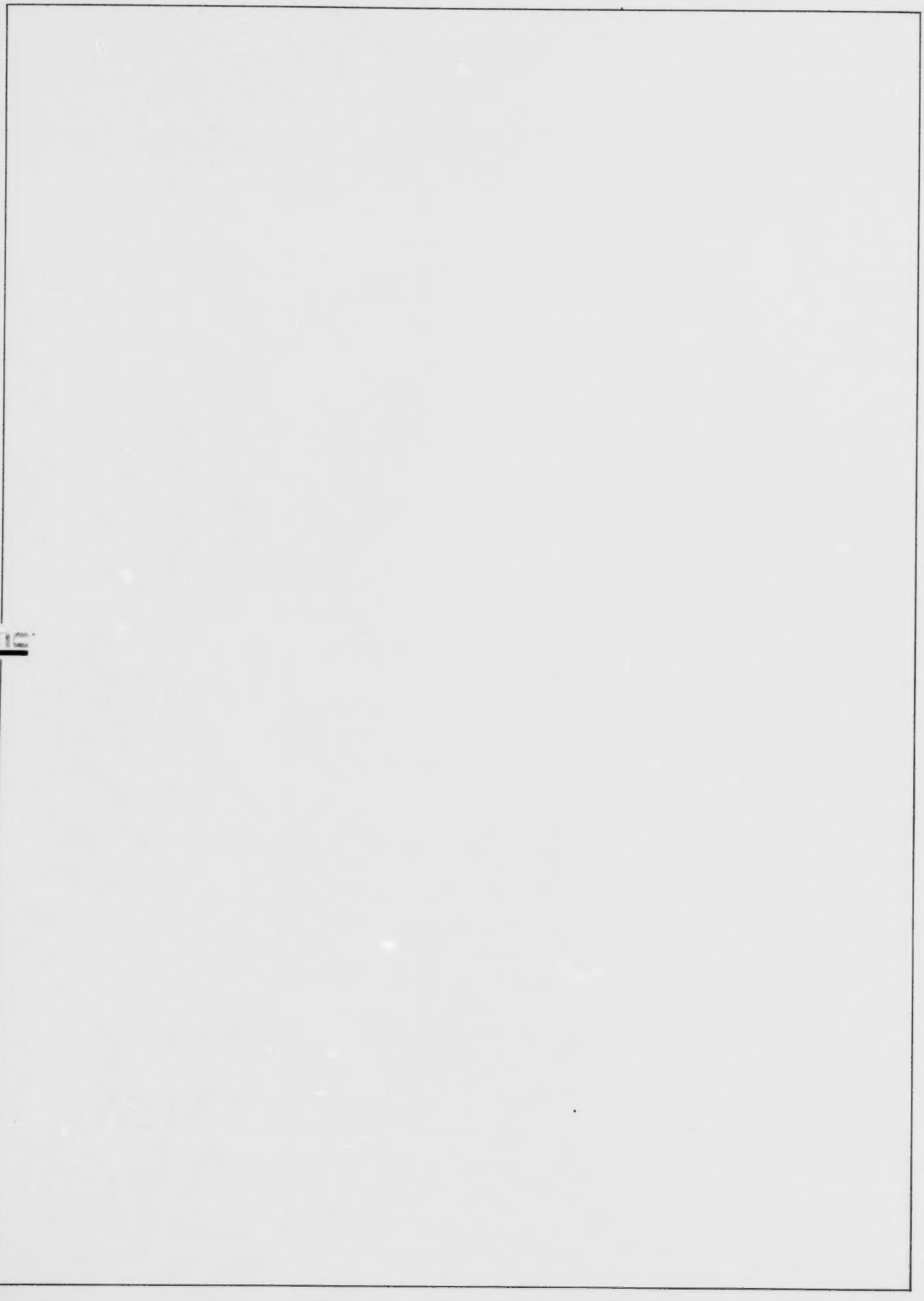
STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
LONG TERM DEBT	1	0	0	0
NET INCOME		91832	97181	102798
CAPITAL COST ALLOWANCE		24061	24061	24061
TOTAL		115893	121243	126859
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
CAPITALIZED INTEREST		0	0	0
LOAN PRINCIPAL	1	0	0	0
TOTAL		0	0	0
GENERATED CASH		115893	121243	126859
EQUITY CASH FLOW		115893	121243	126859
ACCUMULATED CASH FLOW		810501	931744	1058603
DEBT COVERAGE RATIO		0.00	0.00	0.00

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	16.71	12.94
PAYBACK PERIOD-YEARS	7.19	9.63
TERMINAL WORTH	22632	73662

APPENDIX E-2 FINANCIAL ANALYSES (HYDROGEN QUENCH)

- in constant dollars with no escalation assuming 10% equity financing
- in current dollars with 5% escalation per annum assuming 40% debt financing at 12% interest rate per year



LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

P R O F I T A N D L O S S S T A T E M E N T

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	208680	231870	231870	231870	231870	231870	231870
HYDROGEN		0	0	0	75840	84270	84270	84270	84270	84270	84270
LPG		0	0	0	36110	40120	40120	40120	40120	40120	40120
TOTAL		0	0	0	320630	356260	356260	356260	356260	356260	356260
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	109170	121300	121300	121300	121300	121300	121300
ELECTRICITY		0	0	0	86400	96000	96000	96000	96000	96000	96000
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	16890	18460	18460	18460	18460	18460	18460
MAKE-UP WATER		0	0	0	432	465	465	465	465	465	465
ROYALTIES(10 YEARS)		0	0	0	3500	3890	3890	3890	3890	3890	3890
LABOUR/SUP. & OP. SUPPLY		0	0	0	2610	2610	2610	2610	2610	2610	2610
MAINTEN. (INCL. LABOUR)		0	0	0	17760	17760	17760	17760	17760	17760	17760
PROP. TAXES & INSURANCE		0	0	0	8880	8880	8880	8880	8880	8880	8880
OVERHEAD/ADMINISTRATION		0	0	0	7130	7130	7130	7130	7130	7130	7130
SUBTOTAL		0	0	0	252772	276495	276495	276495	276495	276495	276495
CAPITAL COST ALLOWANCE		0	0	0	27654	27654	27654	27654	27654	23292	23292
SUBTOTAL		0	0	0	27654	27654	27654	27654	27654	23292	23292
TOTAL		0	0	0	280426	304149	304149	304149	304149	299787	299787
GROSS INCOME		0	0	0	40204	52111	52111	52111	52111	56473	56473
TAXABLE INCOME		0	0	0	40204	52111	52111	52111	52111	56473	56473
INCOME TAX		0	0	0	14875	19281	19281	19281	19281	20895	20895
NET INCOME		0	0	0	25328	32830	32830	32830	32830	35578	35578
RETURN ON SALES-%		0.00	0.00	0.00	7.90	9.22	9.22	9.22	9.22	9.99	9.99
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	5.18	6.72	6.72	6.72	6.72	7.28	7.28

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		231870	231870	231870	231870	231870	231870	231870	231870	231870	231870
HYDROGEN		84270	84270	84270	84270	84270	84270	84270	84270	84270	84270
LPG		40120	40120	40120	40120	40120	40120	40120	40120	40120	40120
TOTAL		356260	356260	356260	356260	356260	356260	356260	356260	356260	356260
ANNUAL EXPENSES											
NATURAL GAS		121300	121300	121300	121300	121300	121300	121300	121300	121300	121300
ELECTRICITY		96000	96000	96000	96000	96000	96000	96000	96000	96000	96000
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		18460	18460	18460	18460	18460	18460	18460	18460	18460	18460
MAKE-UP WATER		465	465	465	465	465	465	465	465	465	465
ROYALTIES(10 YEARS)		3890	3890	3890	0	0	0	0	0	0	0
LABOUR/SUP. & OP. SUPPLY		2610	2610	2610	2610	2610	2610	2610	2610	2610	2610
MAINTEN. (INCL. LABOUR)		17760	17760	17760	17760	17760	17760	17760	17760	17760	17760
PROP. TAXES & INSURANCE		8880	8880	8880	8880	8880	8880	8880	8880	8880	8880
OVERHEAD/ADMINISTRATION		7130	7130	7130	7130	7130	7130	7130	7130	7130	7130
SUBTOTAL		276495	276495	276495	272605	272605	272605	272605	272605	272605	272605
CAPITAL COST ALLOWANCE		23292	23292	23292	23292	23292	23292	23292	23292	23292	23292
SUBTOTAL		23292	23292	23292	23292	23292	23292	23292	23292	23292	23292
TOTAL		299787	299787	299787	295897	295897	295897	295897	295897	295897	295897
GROSS INCOME		56473	56473	56473	60363	60363	60363	60363	60363	60363	60363
TAXABLE INCOME		56473	56473	56473	60363	60363	60363	60363	60363	60363	60363
INCOME TAX		20895	20895	20895	22334	22334	22334	22334	22334	22334	22334
NET INCOME		35578	35578	35578	38028	38028	38028	38028	38028	38028	38028
RETURN ON SALES-%		9.99	9.99	9.99	10.67	10.67	10.67	10.67	10.67	10.67	10.67
RETURN ON FIXED ASSETS-%		7.28	7.28	7.28	7.78	7.78	7.78	7.78	7.78	7.78	7.78

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		231870	231870	231870
HYDROGEN		84270	84270	84270
LPG		40120	40120	40120
TOTAL		356260	356260	356260
ANNUAL EXPENSES				
NATURAL GAS		121300	121300	121300
ELECTRICITY		96000	96000	96000
QUENCH(HYDROGEN)		0	0	0
CATALYST & CHEMICALS		18460	18460	18460
MAKE-UP WATER		465	465	465
ROYALTIES(10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		2610	2610	2610
MAINTEN. (INCL. LABOUR)		17760	17760	17760
PROP. TAXES & INSURANCE		8880	8880	8880
OVERHEAD/ADMINISTRATION		7130	7130	7130
SUBTOTAL		272605	272605	272605
CAPITAL COST ALLOWANCE		23292	23292	23292
SUBTOTAL		23292	23292	23292
TOTAL		295897	295897	295897
GROSS INCOME		60363	60363	60363
TAXABLE INCOME		60363	60363	60363
INCOME TAX		22334	22334	22334
NET INCOME		38028	38028	38028
RETURN ON SALES-%		10.67	10.67	10.67
RETURN ON FIXED ASSETS-%		7.78	7.78	7.78

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		117622	250105	175375	0	0	0	0	0	0	0
NET INCOME		0	0	0	25328	32830	32830	32830	32830	35578	35578
CAPITAL COST ALLOWANCE		0	0	0	27654	27654	27654	27654	27654	23292	23292
TOTAL		117622	250105	175375	52983	60484	60484	60484	60484	58870	58870
APPLICATIONS OF FUNDS											
LAND		1200	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		130262	284210	177630	0	0	0	0	0	0	0
SUBSIDY:CAP. COSTS		-15630	-34105	-21315	-17765	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-18720	-18720	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	2260	0	0	0	0	0	0	0
START-UP COSTS		0	0	17760	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	17760	0	0	0	0	0	0	0
TOTAL		117622	250105	175375	-36485	0	0	0	0	0	0
GENERATED CASH		0	0	0	89468	60484	60484	60484	60484	58870	58870
EQUITY CASH FLOW		-117622	-250105	-175375	89468	60484	60484	60484	60484	58870	58870
ACCUMULATED CASH FLOW		-117622	-367727	-543102	-453634	-393150	-332666	-272182	-211698	-152828	-93958

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
NET INCOME		35578	35578	35578	38028	38028	38028	38028	38028	38028	38028
CAPITAL COST ALLOWANCE		23292	23292	23292	23292	23292	23292	23292	23292	23292	23292
TOTAL		58870	58870	58870	61321	61321	61321	61321	61321	61321	61321
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COSTS		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
TOTAL		0	0	0	0	0	0	0	0	0	0
GENERATED CASH		58870	58870	58870	61321	61321	61321	61321	61321	61321	61321
EQUITY CASH FLOW		58870	58870	58870	61321	61321	61321	61321	61321	61321	61321
ACCUMULATED CASH FLOW		-35088	23782	82653	143973	205294	266615	327936	389257	450577	511898

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
NET INCOME		38028	38028	38028
CAPITAL COST ALLOWANCE		23292	23292	23292
TOTAL		61321	61321	61321
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COSTS		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
TOTAL		0	0	0
GENERATED CASH		61321	61321	61321
EQUITY CASH FLOW		61321	61321	61321
ACCUMULATED CASH FLOW		573219	634540	695861

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	12.55	9.01
PAYBACK PERIOD-YEARS	6.50	8.60
TERMINAL WORTH	18960	65674

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	266338	310728	326264	342578	359706	377692	396576
HYDROGEN		0	0	0	96793	112930	118576	124505	130730	137267	144130
LPG		0	0	0	46087	53765	56453	59276	62239	65351	68619
TOTAL		0	0	0	409218	477422	501293	526358	552676	580310	609325
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	139332	162554	170681	179215	188176	197585	207464
ELECTRICITY		0	0	0	110271	128649	135082	141836	148928	156374	164193
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	21556	24738	25975	27274	28638	30069	31573
MAKE-UP WATER		0	0	0	551	623	654	687	721	757	795
ROYALTIES (10 YEARS)		0	0	0	3500	3890	3890	3890	3890	3890	3890
LABOUR/SUP. & OP. SUPPLY		0	0	0	3331	3498	3673	3856	4049	4251	4464
MAINTEN.(INCL. LABOUR)		0	0	0	22667	23800	24990	26240	27552	28929	30376
PROP. TAXES & INSURANCE		0	0	0	11333	11900	12495	13120	13776	14465	15188
OVERHEAD/ADMINISTRATION		0	0	0	9100	9555	10033	10534	11061	11614	12195
SUBTOTAL		0	0	0	321641	369207	387473	406652	426790	447935	470147
CAPITAL COST ALLOWANCE		0	0	0	34303	34303	34303	34303	34303	28975	28975
INTEREST EXPENSE-LOAN 1		0	0	0	36513	34433	32102	29492	26569	23295	19628
SUBTOTAL		0	0	0	70817	68736	66406	63796	60872	52270	48603
TOTAL		0	0	0	392458	437943	453878	470447	487662	500205	518749
GROSS INCOME		0	0	0	16760	39480	47415	55911	65014	80105	90585
TAXABLE INCOME		0	0	0	16760	39480	47415	55911	65014	80105	90585
INCOME TAX		0	0	0	6201	14607	17544	20687	24055	29639	33517
NET INCOME		0	0	0	10559	24872	29872	35224	40959	50466	57069
RETURN ON SALES-%		0.00	0.00	0.00	2.58	5.21	5.96	6.69	7.41	8.70	9.37
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	1.74	4.09	4.92	5.80	6.74	8.31	9.39

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		416405	437225	459087	482041	506143	531450	558022	585923	615220	645981
HYDROGEN		151337	158904	166849	175191	183951	193148	202806	212946	223593	234773
LPG		72050	75652	79435	83407	87577	91956	96553	101381	106450	111773
TOTAL		639792	671781	705370	740638	777670	816554	857381	900251	945263	992526
ANNUAL EXPENSES											
NATURAL GAS		217837	228729	240166	252174	264783	278022	291923	306519	321845	337937
ELECTRICITY		172402	181022	190073	199577	209556	220034	231035	242587	254716	267452
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		33151	34809	36550	38377	40296	42311	44426	46647	48980	51429
MAKE-UP WATER		835	877	921	967	1015	1066	1119	1175	1234	1295
ROYALTIES (10 YEARS)		3890	3890	3890	0	0	0	0	0	0	0
LABOUR/SUP. & OP. SUPPLY		4687	4922	5168	5426	5697	5982	6281	6595	6925	7271
MAINTEN.(INCL. LABOUR)		31894	33489	35164	36922	38768	40706	42742	44879	47123	49479
PROP. TAXES & INSURANCE		15947	16745	17582	18461	19384	20353	21371	22439	23561	24739
OVERHEAD/ADMINISTRATION		12804	13445	14117	14823	15564	16342	17159	18017	18918	19864
SUBTOTAL		493449	517927	543629	566726	595062	624815	656056	688859	723302	759467
CAPITAL COST ALLOWANCE		28975	28975	28975	28975	28975	28975	28975	28975	28975	28975
INTEREST EXPENSE-LOAN 1		15521	10922	5770	0	0	0	0	0	0	0
SUBTOTAL		44496	39896	34745	28975	28975	28975	28975	28975	28975	28975
TOTAL		537945	557824	578374	595701	624037	653790	685031	717833	752276	788442
GROSS INCOME		101846	113957	126996	144938	153633	162764	172351	182417	192987	204085
TAXABLE INCOME		101846	113957	126996	144938	153633	162764	172351	182417	192987	204085
INCOME TAX		37683	42164	46989	53627	56844	60223	63770	67494	71405	75511
NET INCOME		64163	71793	80008	91311	96789	102541	108581	114923	121582	128573
RETURN ON SALES-%		10.03	10.69	11.34	12.33	12.45	12.56	12.66	12.77	12.86	12.95
RETURN ON FIXED ASSETS-%		10.56	11.82	13.17	15.03	15.93	16.88	17.87	18.91	20.01	21.16

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		678280	712194	747803
HYDROGEN		246512	258837	271779
LPG		117361	123229	129391
TOTAL		1042152	1094260	1148973
ANNUAL EXPENSES				
NATURAL GAS		354834	372575	391204
ELECTRICITY		280825	294866	309609
QUENCH(HYDROGEN)		0	0	0
CATALYST & CHEMICALS		54000	56700	59535
MAKE-UP WATER		1360	1428	1500
ROYALTIES (10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		7635	8017	8418
MAINTEN.(INCL. LABOUR)		51953	54550	57278
PROP. TAXES & INSURANCE		25974	27275	28639
OVERHEAD/ADMINISTRATION		20857	21900	22995
SUBTOTAL		797440	837312	879177
CAPITAL COST ALLOWANCE		28975	28975	28975
INTEREST EXPENSE-LOAN 1		0	0	0
SUBTOTAL		28975	28975	28975
TOTAL		826415	866287	908152
GROSS INCOME		215738	227973	240821
TAXABLE INCOME		215738	227973	240821
INCOME TAX		79823	84350	89104
NET INCOME		135915	143623	151717
RETURN ON SALES-%		13.04	13.13	13.20
RETURN ON FIXED ASSETS-%		22.37	23.64	24.97

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		78414	173717	119899	0	0	0	0	0	0	0
LONG TERM DEBT	1	54146	129257	120875	0	0	0	0	0	0	0
NET INCOME		0	0	0	10559	24872	29872	35224	40959	50466	57069
CAPITAL COST ALLOWANCE		0	0	0	34303	34303	34303	34303	34303	28975	28975
TOTAL		132560	302974	240774	44862	59175	64175	69527	75262	79441	86044
APPLICATIONS OF FUNDS											
LAND		1323	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		143614	329009	215910	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		-17232	-39481	-25909	-22673	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-22754	-23892	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	2747	0	0	0	0	0	0	0
START-UP COSTS		0	0	21587	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	21587	0	0	0	0	0	0	0
CAPITALIZED INTEREST		3065	13446	27605	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	0	0	0	17339	19420	21750	24360	27283	30557	34224
TOTAL		132560	302974	240774	-29226	19420	21750	24360	27283	30557	34224
GENERATED CASH		0	0	0	74088	39756	42425	45167	47979	48884	51819
EQUITY CASH FLOW		-78414	-173717	-119899	74088	39756	42425	45167	47979	48884	51819
ACCUMULATED CASH FLOW		-78414	-252130	-372029	-297941	-258185	-215761	-170593	-122615	-73731	-21911
DEBT COVERAGE RATIO		0.00	0.00	0.00	2.38	1.74	1.79	1.84	1.89	1.91	1.96

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
LONG TERM DEBT	1	0	0	0	0	0	0	0	0	0	0
NET INCOME		64163	71793	80008	91311	96789	102541	108581	114923	121582	128573
CAPITAL COST ALLOWANCE		28975	28975	28975	28975	28975	28975	28975	28975	28975	28975
TOTAL		93138	100768	108983	120286	125764	131516	137556	143898	150556	157548
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
CAPITALIZED INTEREST		0	0	0	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	38331	42931	48083	0	0	0	0	0	0	0
TOTAL		38331	42931	48083	0	0	0	0	0	0	0
GENERATED CASH		54807	57837	60900	120286	125764	131516	137556	143898	150556	157548
EQUITY CASH FLOW		54807	57837	60900	120286	125764	131516	137556	143898	150556	157548
ACCUMULATED CASH FLOW		32895	90732	151633	271918	397682	529198	666754	810651	961208	1118756
DEBT COVERAGE RATIO		2.02	2.07	2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
LONG TERM DEBT	1	0	0	0
NET INCOME		135915	143623	151717
CAPITAL COST ALLOWANCE		28975	28975	28975
TOTAL		164890	172598	180692
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
CAPITALIZED INTEREST		0	0	0
LOAN PRINCIPAL	1	0	0	0
TOTAL		0	0	0
GENERATED CASH		164890	172598	180692
EQUITY CASH FLOW		164890	172598	180692
ACCUMULATED CASH FLOW		1283646	1456244	1636935
DEBT COVERAGE RATIO		0.00	0.00	0.00

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	20.18	15.52
PAYBACK PERIOD-YEARS	5.50	7.40
TERMINAL WORTH	25938	82156

APPENDIX E-3 FINANCIAL ANALYSES (LPG QUENCH)

- in constant dollars with no escalation assuming 10% equity financing
- in current dollars with 5% escalation per annum assuming 40% debt financing at 12% interest rate per year

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	208680	231870	231870	231870	231870	231870	231870
HYDROGEN		0	0	0	60075	66750	66750	66750	66750	66750	66750
LPG		0	0	0	0	0	0	0	0	0	0
TOTAL		0	0	0	268755	298620	298620	298620	298620	298620	298620
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	84330	93700	93700	93700	93700	93700	93700
ELECTRICITY		0	0	0	61200	68000	68000	68000	68000	68000	68000
QUENCH(LPG)		0	0	0	29860	33180	33180	33180	33180	33180	33180
CATALYST & CHEMICALS		0	0	0	15980	17220	17220	17220	17220	17220	17220
MAKE-UP WATER		0	0	0	320	346	346	346	346	346	346
ROYALTIES(10 YEARS)		0	0	0	2835	3150	3150	3150	3150	3150	3150
LABOUR/SUP. & OP. SUPPLY		0	0	0	2610	2610	2610	2610	2610	2610	2610
MAINTEN. (INCL. LABOUR)		0	0	0	15870	15870	15870	15870	15870	15870	15870
PROP. TAXES & INSURANCE		0	0	0	7930	7930	7930	7930	7930	7930	7930
OVERHEAD/ADMINISTRATION		0	0	0	6470	6470	6470	6470	6470	6470	6470
SUBTOTAL		0	0	0	227405	248476	248476	248476	248476	248476	248476
CAPITAL COST ALLOWANCE		0	0	0	24339	24339	24339	24339	24339	20459	20459
SUBTOTAL		0	0	0	24339	24339	24339	24339	24339	20459	20459
TOTAL		0	0	0	251744	272815	272815	272815	272815	268935	268935
GROSS INCOME		0	0	0	17011	25805	25805	25805	25805	29685	29685
TAXABLE INCOME		0	0	0	17011	25805	25805	25805	25805	29685	29685
INCOME TAX		0	0	0	6294	9548	9548	9548	9548	10983	10983
NET INCOME		0	0	0	10717	16257	16257	16257	16257	18701	18701
RETURN ON SALES-%		0.00	0.00	0.00	3.99	5.44	5.44	5.44	5.44	6.26	6.26
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	2.49	3.78	3.78	3.78	3.78	4.35	4.35

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		231870	231870	231870	231870	231870	231870	231870	231870	231870	231870
HYDROGEN		66750	66750	66750	66750	66750	66750	66750	66750	66750	66750
LPG		0	0	0	0	0	0	0	0	0	0
TOTAL		298620	298620	298620	298620	298620	298620	298620	298620	298620	298620
ANNUAL EXPENSES											
NATURAL GAS		93700	93700	93700	93700	93700	93700	93700	93700	93700	93700
ELECTRICITY		68000	68000	68000	68000	68000	68000	68000	68000	68000	68000
QUENCH(LPG)		33180	33180	33180	33180	33180	33180	33180	33180	33180	33180
CATALYST & CHEMICALS		17220	17220	17220	17220	17220	17220	17220	17220	17220	17220
MAKE-UP WATER		346	346	346	346	346	346	346	346	346	346
ROYALTIES(10 YEARS)		3150	3150	3150	0	0	0	0	0	0	0
LABOUR/SUP. & OP. SUPPLY		2610	2610	2610	2610	2610	2610	2610	2610	2610	2610
MAINTEN. (INCL. LABOUR)		15870	15870	15870	15870	15870	15870	15870	15870	15870	15870
PROP. TAXES & INSURANCE		7930	7930	7930	7930	7930	7930	7930	7930	7930	7930
OVERHEAD/ADMINISTRATION		6470	6470	6470	6470	6470	6470	6470	6470	6470	6470
SUBTOTAL		248476	248476	248476	245326	245326	245326	245326	245326	245326	245326
CAPITAL COST ALLOWANCE		20459	20459	20459	20459	20459	20459	20459	20459	20459	20459
SUBTOTAL		20459	20459	20459	20459	20459	20459	20459	20459	20459	20459
TOTAL		268935	268935	268935	265785	265785	265785	265785	265785	265785	265785
GROSS INCOME		29685	29685	29685	32835	32835	32835	32835	32835	32835	32835
TAXABLE INCOME		29685	29685	29685	32835	32835	32835	32835	32835	32835	32835
INCOME TAX		10983	10983	10983	12149	12149	12149	12149	12149	12149	12149
NET INCOME		18701	18701	18701	20686	20686	20686	20686	20686	20686	20686
RETURN ON SALES-%		6.26	6.26	6.26	6.93	6.93	6.93	6.93	6.93	6.93	6.93
RETURN ON FIXED ASSETS-%		4.35	4.35	4.35	4.81	4.81	4.81	4.81	4.81	4.81	4.81

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		231870	231870	231870
HYDROGEN		66750	66750	66750
LPG		0	0	0
TOTAL		298620	298620	298620
ANNUAL EXPENSES				
NATURAL GAS		93700	93700	93700
ELECTRICITY		68000	68000	68000
QUENCH(LPG)		33180	33180	33180
CATALYST & CHEMICALS		17220	17220	17220
MAKE-UP WATER		346	346	346
ROYALTIES(10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		2610	2610	2610
MAINTEN. (INCL. LABOUR)		15870	15870	15870
PROP. TAXES & INSURANCE		7930	7930	7930
OVERHEAD/ADMINISTRATION		6470	6470	6470
SUBTOTAL		245326	245326	245326
CAPITAL COST ALLOWANCE		20459	20459	20459
SUBTOTAL		20459	20459	20459
TOTAL		265785	265785	265785
GROSS INCOME		32835	32835	32835
TAXABLE INCOME		32835	32835	32835
INCOME TAX		12149	12149	12149
NET INCOME		20686	20686	20686
RETURN ON SALES-%		6.93	6.93	6.93
RETURN ON FIXED ASSETS-%		4.81	4.81	4.81

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		105390	223405	152920	0	0	0	0	0	0	0
NET INCOME		0	0	0	10717	16257	16257	16257	16257	18701	18701
CAPITAL COST ALLOWANCE		0	0	0	24339	24339	24339	24339	24339	20459	20459
TOTAL		105390	223405	152920	35056	40596	40596	40596	40596	39161	39161
APPLICATIONS OF FUNDS											
LAND		1200	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		116360	253870	158670	0	0	0	0	0	0	0
SUBSIDY:CAP. COSTS		-13960	-30465	-19040	-15870	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-20190	-20190	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	1740	0	0	0	0	0	0	0
START-UP COSTS		0	0	15870	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	15870	0	0	0	0	0	0	0
TOTAL		105390	223405	152920	-36060	0	0	0	0	0	0
GENERATED CASH		0	0	0	71116	40596	40596	40596	40596	39161	39161
EQUITY CASH FLOW		-105390	-223405	-152920	71116	40596	40596	40596	40596	39161	39161
ACCUMULATED CASH FLOW		-105390	-328795	-481715	-410599	-370003	-329407	-288810	-248214	-209053	-169893

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
NET INCOME		18701	18701	18701	20686	20686	20686	20686	20686	20686	20686
CAPITAL COST ALLOWANCE		20459	20459	20459	20459	20459	20459	20459	20459	20459	20459
TOTAL		39161	39161	39161	41145	41145	41145	41145	41145	41145	41145
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COSTS		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
TOTAL		0	0	0	0	0	0	0	0	0	0
GENERATED CASH		39161	39161	39161	41145	41145	41145	41145	41145	41145	41145
EQUITY CASH FLOW		39161	39161	39161	41145	41145	41145	41145	41145	41145	41145
ACCUMULATED CASH FLOW		-130732	-91571	-52411	-11266	29880	71025	112170	153315	194460	235605

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CONSTANT DOLLARS JANUARY 1986 ('000) - 100% EQUITY

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
NET INCOME		20686	20686	20686
CAPITAL COST ALLOWANCE		20459	20459	20459
TOTAL		41145	41145	41145
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COSTS		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
TOTAL		0	0	0
GENERATED CASH		41145	41145	41145
EQUITY CASH FLOW		41145	41145	41145
ACCUMULATED CASH FLOW		276750	317896	359041

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	8.32	6.06
PAYBACK PERIOD-YEARS	9.06	11.27
TERMINAL WORTH	17070	61365

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	266334	310728	326264	342578	359706	377692	396576
HYDROGEN		0	0	0	76673	89451	93924	98620	103551	108729	114165
LPG		0	0	0	0	0	0	0	0	0	0
TOTAL		0	0	0	343007	400179	420188	441198	463258	486420	510741
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	107629	125567	131845	138438	145359	152627	160259
ELECTRICITY		0	0	0	78108	91126	95683	100467	105490	110765	116303
QUENCH(LPG)		0	0	0	38110	44464	46688	49022	51473	54047	56749
CATALYST & CHEMICALS		0	0	0	20395	23076	24230	25442	26714	28050	29452
MAKE-UP WATER		0	0	0	408	464	487	511	537	564	592
ROYALTIES(10 YEARS)		0	0	0	2835	3150	3150	3150	3150	3150	3150
LABOUR/SUP. & OP. SUPPLY		0	0	0	3331	3498	3673	3856	4049	4251	4464
MAINTEN. (INCL. LABOUR)		0	0	0	20255	21267	22331	23447	24620	25851	27143
PROP. TAXES & INSURANCE		0	0	0	10121	10627	11158	11716	12302	12917	13563
OVERHEAD/ADMINISTRATION		0	0	0	8258	8670	9104	9559	10037	10539	11066
SUBTOTAL		0	0	0	289450	331910	348348	365608	383731	402760	422741
CAPITAL COST ALLOWANCE		0	0	0	30182	30182	30182	30182	30182	25450	25450
INTEREST EXPENSE-LOAN 1		0	0	0	32626	30766	28684	26352	23740	20815	17538
SUBTOTAL		0	0	0	62807	60948	58866	56534	53922	46265	42988
TOTAL		0	0	0	352257	392858	407214	422142	437653	449025	465729
GROSS INCOME		0	0	0	-9250	7321	12974	19056	25605	37396	45013
TAXABLE INCOME		0	0	0	-9250	7321	12974	19056	25605	37396	45013
INCOME TAX		0	0	0	0	2709	4800	7051	9474	13836	16655
NET INCOME		0	0	0	-9250	4612	8174	12005	16131	23559	28358
RETURN ON SALES-%		0.00	0.00	0.00	-2.70	1.15	1.95	2.72	3.48	4.84	5.55
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	0.00	0.86	1.53	2.25	3.02	4.41	5.31

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		416405	437225	459087	482041	506143	531450	558022	585923	615220	645981
HYDROGEN		119873	125867	132160	138768	145707	152992	160642	168674	177108	185963
LPG		0	0	0	0	0	0	0	0	0	0
TOTAL		536278	563092	591247	620809	651850	684442	718664	754597	792327	831943
ANNUAL EXPENSES											
NATURAL GAS		168272	176685	185520	194795	204535	214762	225500	236775	248614	261045
ELECTRICITY		122118	128224	134635	141367	148435	155857	163650	171833	180424	189445
QUENCH(LPG)		59586	62566	65694	68979	72428	76049	79852	83844	88036	92438
CATALYST & CHEMICALS		30925	32471	34094	35799	37589	39469	41442	43514	45690	47974
MAKE-UP WATER		621	652	685	719	755	793	833	874	918	964
ROYALTIES(10 YEARS)		3150	3150	3150	0	0	0	0	0	0	0
LABOUR/SUP. & OP. SUPPLY		4687	4922	5168	5426	5697	5982	6281	6595	6925	7271
MAINTEN. (INCL. LABOUR)		28500	29925	31422	32993	34642	36374	38193	40103	42108	44213
PROP. TAXES & INSURANCE		14241	14953	15701	16486	17310	18176	19084	20039	21041	22093
OVERHEAD/ADMINISTRATION		11619	12200	12810	13451	14123	14829	15571	16349	17167	18025
SUBTOTAL		443720	465749	488878	510015	535516	562291	590406	619926	650922	683469
CAPITAL COST ALLOWANCE		25450	25450	25450	25450	25450	25450	25450	25450	25450	25450
INTEREST EXPENSE-LOAN 1		13869	9759	5156	0	0	0	0	0	0	0
SUBTOTAL		39319	35209	30605	25450	25450	25450	25450	25450	25450	25450
TOTAL		483039	500957	519484	535465	560965	587741	615856	645376	676372	708918
GROSS INCOME		53240	62135	71763	85345	90884	96701	102808	109221	115955	123025
TAXABLE INCOME		53240	62135	71763	85345	90884	96701	102808	109221	115955	123025
INCOME TAX		19699	22990	26552	31577	33627	35779	38039	40412	42903	45519
NET INCOME		33541	39145	45211	53767	57257	60922	64769	68809	73051	77506
RETURN ON SALES-%		6.25	6.95	7.65	8.66	8.78	8.90	9.01	9.12	9.22	9.32
RETURN ON FIXED ASSETS-%		6.28	7.33	8.46	10.07	10.72	11.41	12.13	12.88	13.68	14.51

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		678280	712194	747803
HYDROGEN		195261	205024	215275
LPG		0	0	0
TOTAL		873541	917218	963078
ANNUAL EXPENSES				
NATURAL GAS		274097	287802	302192
ELECTRICITY		198918	208863	219307
QUENCH(LPG)		97060	101913	107009
CATALYST & CHEMICALS		50373	52892	55536
MAKE-UP WATER		1012	1063	1116
ROYALTIES(10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		7635	8017	8418
MAINTEN. (INCL. LABOUR)		46424	48745	51182
PROP. TAXES & INSURANCE		23197	24357	25575
OVERHEAD/ADMINISTRATION		18926	19873	20866
SUBTOTAL		717642	753524	791200
CAPITAL COST ALLOWANCE		25450	25450	25450
INTEREST EXPENSE-LOAN 1		0	0	0
SUBTOTAL		25450	25450	25450
TOTAL		743092	778974	816650
GROSS INCOME		130449	138244	146428
TAXABLE INCOME		130449	138244	146428
INCOME TAX		48266	51150	54179
NET INCOME		82183	87094	92250
RETURN ON SALES-%		9.41	9.50	9.58
RETURN ON FIXED ASSETS-%		15.39	16.30	17.27

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		70323	155171	102555	0	0	0	0	0	0	0
LONG TERM DEBT	1	48427	115466	107987	0	0	0	0	0	0	0
NET INCOME		0	0	0	-9250	4612	8174	12005	16131	23559	28358
CAPITAL COST ALLOWANCE		0	0	0	30182	30182	30182	30182	30182	25450	25450
TOTAL		118750	270637	210542	20932	34794	38355	42187	46313	49009	53808
APPLICATIONS OF FUNDS											
LAND		1323	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		128287	293886	192864	0	0	0	0	0	0	0
SUBSIDY:CAP. COSTS		-15391	-35267	-23143	-20255	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-24541	-25768	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	2115	0	0	0	0	0	0	0
START-UP COSTS		0	0	19290	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	19290	0	0	0	0	0	0	0
CAPITALIZED INTEREST		2741	12018	24666	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	0	0	0	15493	17352	19434	21766	24378	27304	30580
TOTAL		118750	270637	210542	-30530	17352	19434	21766	24378	27304	30580
GENERATED CASH		0	0	0	51462	17442	18921	20420	21934	21705	23228
EQUITY CASH FLOW		-70323	-155171	-102555	51462	17442	18921	20420	21934	21705	23228
ACCUMULATED CASH FLOW		-70323	-225494	-328049	-276587	-259146	-240225	-219804	-197870	-176165	-152937
DEBT COVERAGE RATIO		0.00	0.00	0.00	2.07	1.36	1.39	1.42	1.46	1.45	1.48

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
LONG TERM DEBT	1	0	0	0	0	0	0	0	0	0	0
NET INCOME		33541	39145	45211	53767	57257	60922	64769	68809	73051	77506
CAPITAL COST ALLOWANCE		25450	25450	25450	25450	25450	25450	25450	25450	25450	25450
TOTAL		58991	64595	70661	79217	82707	86371	90219	94259	98501	102956
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COSTS		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
CAPITALIZED INTEREST		0	0	0	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	34250	38360	42963	0	0	0	0	0	0	0
TOTAL		34250	38360	42963	0	0	0	0	0	0	0
GENERATED CASH		24741	26235	27698	79217	82707	86371	90219	94259	98501	102956
EQUITY CASH FLOW		24741	26235	27698	79217	82707	86371	90219	94259	98501	102956
ACCUMULATED CASH FLOW		-128196	-101961	-74263	4954	87661	174032	264252	358511	457012	559968
DEBT COVERAGE RATIO		1.51	1.55	1.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
LONG TERM DEBT	1	0	0	0
NET INCOME		82183	87094	92250
CAPITAL COST ALLOWANCE		25450	25450	25450
TOTAL		107633	112543	117700
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COSTS		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
CAPITALIZED INTEREST		0	0	0
LOAN PRINCIPAL	1	0	0	0
TOTAL		0	0	0
GENERATED CASH		107633	112543	117700
EQUITY CASH FLOW		107633	112543	117700
ACCUMULATED CASH FLOW		667601	780144	897844
DEBT COVERAGE RATIO		0.00	0.00	0.00

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	14.10	10.91
PAYBACK PERIOD-YEARS	9.09	10.94
TERMINAL WORTH	23641	77056

APPENDIX F-1 SENSITIVITY ANALYSES (ETHANE QUENCH)

- in current dollars with 5% escalation per annum assuming 40% debt financing at 12% interest rate per year

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — TOTAL PLANT COST

ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
MAINTEN.(INCL. LABOUR)		-20.00	-10.00	10.00	20.00
PROP. TAXES & INSURANCE		-20.00	-10.00	10.00	20.00
OVERHEAD/ADMINISTRATION		-17.90	-9.00	8.90	17.90
TOTAL PLANT COST		-20.00	-10.00	10.00	20.00
SUBSIDY:CAP. COST GRANT		-20.00	-10.00	10.00	20.00
SUBSIDY:HYDRO QUEBEC		-20.00	-10.00	10.00	20.00
START-UP COSTS		-20.00	-10.00	10.00	20.00
WORKING CAPITAL		-20.00	-10.00	10.00	20.00
IRR BEFORE TAXES	%	23.01	19.62	14.18	11.93
IRR AFTER TAXES	%	17.66	15.12	11.03	9.32
TERMINAL WORTH (B.T.)	$	18976	20804	24460	26288
TERMINAL WORTH (A.T.)	$	59799	66730	80593	87524
PAYBACK PERIOD (B.T.)	YEARS	4.51	5.71	8.99	10.54
PAYBACK PERIOD (A.T.)	YEARS	6.13	7.68	10.85	11.89
RETURN ON SALES	%	9.32	8.48	6.80	5.96
RETURN ON FIXED ASSETS	%	14.13	11.44	7.52	6.05
DEBT COVERAGE	RATIO				
MINIMUM		1.90	1.68	1.40	1.24
YEAR		1992	1992	1993	1992
MAXIMUM		2.61	2.43	2.09	1.93
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		NATURAL GAS			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
NATURAL GAS		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	18.96	14.35	11.84	9.13
IRR AFTER TAXES	%	14.62	11.16	9.26	7.13
TERMINAL WORTH (B.T.)	$	22632	22632	22632	22632
TERMINAL WORTH (A.T.)	$	73662	73662	73662	73662
PAYBACK PERIOD (B.T.)	YEARS	6.01	8.85	10.60	12.16
PAYBACK PERIOD (A.T.)	YEARS	8.06	10.78	11.94	13.44
RETURN ON SALES	%	8.99	6.29	4.94	3.57
RETURN ON FIXED ASSETS	%	10.93	7.65	6.01	4.35
DEBT COVERAGE	RATIO				
MINIMUM		1.64	1.41	1.23	1.02
YEAR		1992	1993	1992	1992
MAXIMUM		2.39	2.10	1.92	1.74
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — ELECTRICITY

ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
ELECTRICITY		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	18.98	14.33	11.79	9.05
IRR AFTER TAXES	%	14.64	11.15	9.22	7.07
TERMINAL WORTH (B.T.)	$	22632	22632	22632	22632
TERMINAL WORTH (A.T.)	$	73662	73662	73662	73662
PAYBACK PERIOD (B.T.)	YEARS	6.00	8.87	10.63	12.21
PAYBACK PERIOD (A.T.)	YEARS	8.04	10.79	11.96	13.49
RETURN ON SALES	%	9.00	6.28	4.92	3.54
RETURN ON FIXED ASSETS	%	10.94	7.64	5.98	4.30
DEBT COVERAGE	RATIO				
MINIMUM		1.64	1.41	1.23	1.01
YEAR		1992	1993	1992	1992
MAXIMUM		2.39	2.10	1.92	1.73
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		QUENCH(ETHANE)			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
QUENCH(ETHANE)		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	19.37	13.89	10.85	7.48
IRR AFTER TAXES	%	14.93	10.82	8.49	5.79
TERMINAL WORTH (B.T.)	$	22632	22632	22632	22632
TERMINAL WORTH (A.T.)	$	73662	73662	73662	73662
PAYBACK PERIOD (B.T.)	YEARS	5.81	9.24	11.14	13.27
PAYBACK PERIOD (A.T.)	YEARS	7.81	10.98	12.44	14.57
RETURN ON SALES	%	9.24	6.04	4.44	2.76
RETURN ON FIXED ASSETS	%	11.24	7.34	5.39	3.36
DEBT COVERAGE	RATIO				
MINIMUM		1.67	1.40	1.15	1.00
YEAR		1992	1992	1992	1992
MAXIMUM		2.41	2.07	1.85	1.64
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — LPG

ANALYSIS No.			1	2	3	4
DESCRIPTION		L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
LPG			-10.00	10.00	20.00	30.00
IRR BEFORE TAXES		%	15.57	17.83	18.92	19.99
IRR AFTER TAXES		%	12.08	13.78	14.60	15.40
TERMINAL WORTH (B.T.)		$	22632	22632	22632	22632
TERMINAL WORTH (A.T.)		$	73662	73662	73662	73662
PAYBACK PERIOD (B.T.)		YEARS	7.94	6.55	6.02	5.55
PAYBACK PERIOD (A.T.)		YEARS	10.28	8.79	8.08	7.47
RETURN ON SALES		%	7.05	8.22	8.78	9.34
RETURN ON FIXED ASSETS		%	8.48	10.10	10.90	11.71
DEBT COVERAGE		RATIO				
	MINIMUM		1.47	1.57	1.64	1.71
	YEAR		1992	1992	1992	1992
	MAXIMUM		2.19	2.33	2.39	2.45
	YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — HYDROGEN

ANALYSIS No.			1	2	3	4
DESCRIPTION		L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
HYDROGEN			-30.00	-20.00	-10.00	10.00
IRR BEFORE TAXES		%	9.53	12.09	14.47	18.86
IRR AFTER TAXES		%	7.47	9.45	11.25	14.55
TERMINAL WORTH (B.T.)		$	22632	22632	22632	22632
TERMINAL WORTH (A.T.)		$	73662	73662	73662	73662
PAYBACK PERIOD (B.T.)		YEARS	11.91	10.47	8.76	6.05
PAYBACK PERIOD (A.T.)		YEARS	13.19	11.82	10.73	8.12
RETURN ON SALES		%	4.02	5.29	6.49	8.75
RETURN ON FIXED ASSETS		%	4.59	6.17	7.73	10.85
DEBT COVERAGE		RATIO				
	MINIMUM		1.05	1.25	1.41	1.64
	YEAR		1992	1992	1993	1992
	MAXIMUM		1.77	1.94	2.11	2.39
	YEAR		1991	1991	1991	1991

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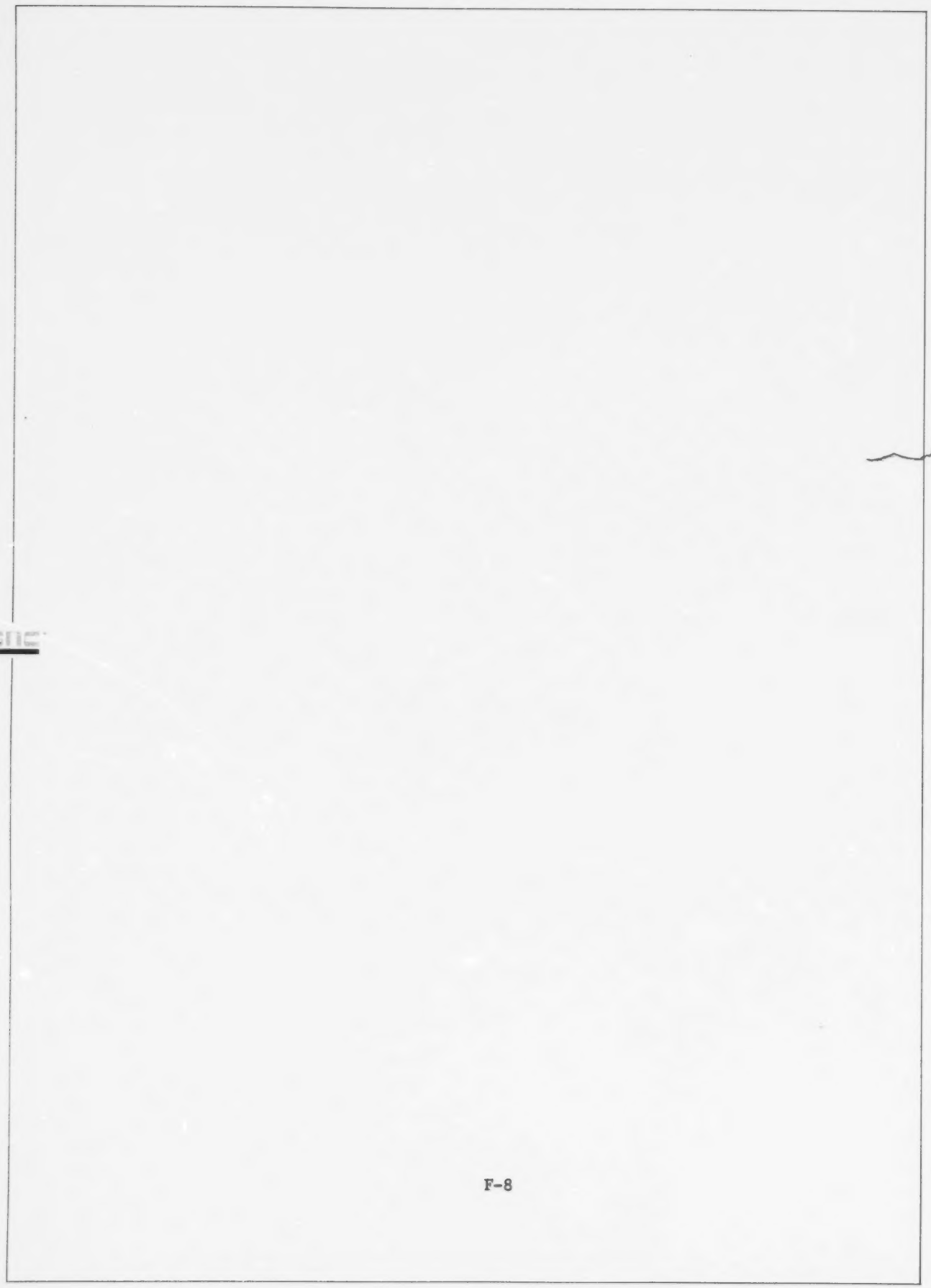
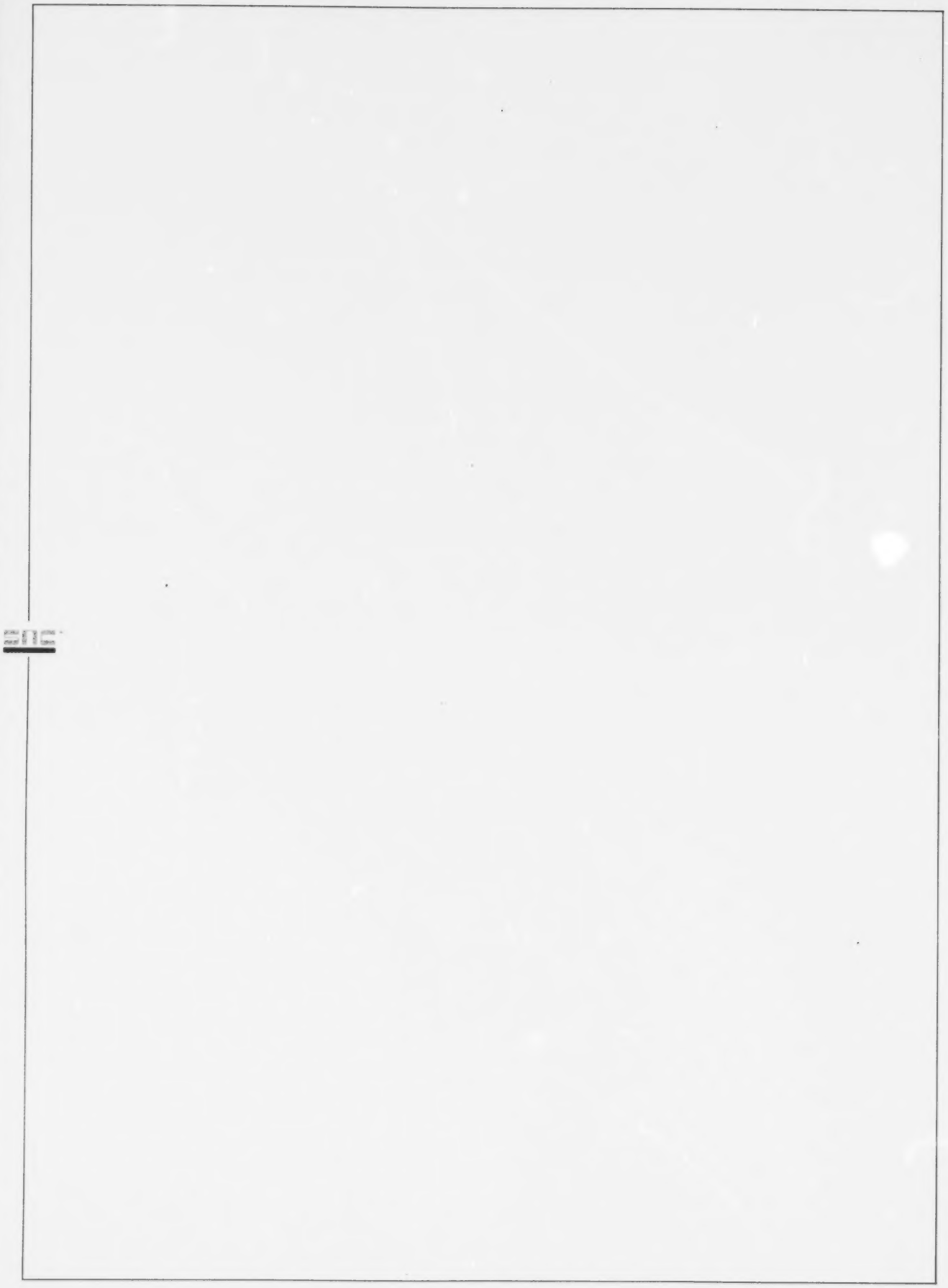
LIQUID FUEL FROM NATURAL GAS (ETHANE QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		GASOLINE			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
GASOLINE		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	8.47	23.65	29.86	35.57
IRR AFTER TAXES	%	6.60	18.12	22.74	26.98
TERMINAL WORTH (B.T.)	$	22632	22632	22632	22632
TERMINAL WORTH (A.T.)	$	73662	73662	73662	73662
PAYBACK PERIOD (B.T.)	YEARS	12.58	4.33	3.07	2.37
PAYBACK PERIOD (A.T.)	YEARS	13.88	5.90	4.27	3.36
RETURN ON SALES	%	3.49	11.22	14.36	17.14
RETURN ON FIXED ASSETS	%	3.95	14.58	19.87	25.17
DEBT COVERAGE	RATIO				
MINIMUM		1.00	1.94	2.37	2.80
YEAR		1992	1992	1992	1992
MAXIMUM		1.70	2.65	3.06	3.69
YEAR		1991	1991	2000	2000



APPENDIX F-2 SENSITIVITY ANALYSES (HYDROGEN QUENCH)

- in current dollars with 5% escalation per annum assuming 40% debt financing at 12% interest rate per year



LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		TOTAL PLANT COST			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
MAINTEN.(INCL. LABOUR)		-20.00	-10.00	10.00	20.00
PROP. TAXES & INSURANCE		-20.00	-10.00	10.00	20.00
OVERHEAD/ADMINISTRATION		-17.30	-8.70	8.70	17.40
TOTAL PLANT COST		-20.00	-10.00	10.00	20.00
SUBSIDY:CAP. COST GRANT		-20.00	-10.00	10.00	20.00
SUBSIDY:HYDRO QUEBEC		-20.00	-10.00	10.00	20.00
START-UP COSTS		-20.00	-10.00	10.00	20.00
WORKING CAPITAL		-20.00	-10.00	10.00	20.00
IRR BEFORE TAXES	%	26.80	23.22	17.55	15.23
IRR AFTER TAXES	%	20.46	17.79	13.55	11.80
TERMINAL WORTH (B.T.)	$	21620	23779	28097	30255
TERMINAL WORTH (A.T.)	$	66595	74376	89937	97717
PAYBACK PERIOD (B.T.)	YEARS	3.63	4.48	6.72	8.17
PAYBACK PERIOD (A.T.)	YEARS	5.00	6.09	9.00	10.40
RETURN ON SALES	%	12.94	12.01	10.14	9.21
RETURN ON FIXED ASSETS	%	17.31	14.30	9.90	8.25
DEBT COVERAGE	RATIO				
MINIMUM		2.18	1.94	1.58	1.47
YEAR		1992	1992	1992	1992
MAXIMUM		2.79	2.54	2.24	2.09
YEAR		2000	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		NATURAL GAS			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
NATURAL GAS		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	23.12	17.08	13.76	10.13
IRR AFTER TAXES	%	17.71	13.20	10.70	7.92
TERMINAL WORTH (B.T.)	$	25938	25938	25938	25938
TERMINAL WORTH (A.T.)	$	82156	82156	82156	82156
PAYBACK PERIOD (B.T.)	YEARS	4.51	7.00	9.36	11.55
PAYBACK PERIOD (A.T.)	YEARS	6.13	9.35	11.04	12.82
RETURN ON SALES	%	13.22	8.93	6.79	4.64
RETURN ON FIXED ASSETS	%	14.18	9.58	7.28	4.98
DEBT COVERAGE	RATIO				
MINIMUM		1.93	1.55	1.41	1.10
YEAR		1992	1992	1992	1992
MAXIMUM		2.54	2.21	1.97	1.71
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — ELECTRICITY

ANALYSIS No.			1	2	3	4
DESCRIPTION		L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
ELECTRICITY			-10.00	10.00	20.00	30.00
IRR BEFORE TAXES		%	22.52	17.74	15.18	12.44
IRR AFTER TAXES		%	17.26	13.70	11.77	9.70
TERMINAL WORTH (B.T.)		$	25938	25938	25938	25938
TERMINAL WORTH (A.T.)		$	82156	82156	82156	82156
PAYBACK PERIOD (B.T.)		YEARS	4.69	6.63	8.23	10.30
PAYBACK PERIOD (A.T.)		YEARS	6.35	8.86	10.43	11.64
RETURN ON SALES		%	12.78	9.38	7.68	5.99
RETURN ON FIXED ASSETS		%	13.70	10.06	8.24	6.42
DEBT COVERAGE		RATIO				
	MINIMUM		1.89	1.59	1.47	1.29
	YEAR		1992	1992	1993	1992
	MAXIMUM		2.50	2.25	2.08	1.88
	YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		QUENCH			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
QUENCH(HYDROGEN)		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	20.18	20.18	20.18	20.18
IRR AFTER TAXES	%	15.52	15.52	15.52	15.52
TERMINAL WORTH (B.T.)	$	25938	25938	25938	25938
TERMINAL WORTH (A.T.)	$	82156	82156	82156	82156
PAYBACK PERIOD (B.T.)	YEARS	5.50	5.50	5.50	5.50
PAYBACK PERIOD (A.T.)	YEARS	7.40	7.40	7.40	7.40
RETURN ON SALES	%	11.08	11.08	11.08	11.08
RETURN ON FIXED ASSETS	%	11.88	11.88	11.88	11.88
DEBT COVERAGE	RATIO				
	MINIMUM	1.74	1.74	1.74	1.74
	YEAR	1992	1992	1992	1992
	MAXIMUM	2.38	2.38	2.38	2.38
	YEAR	1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 obl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		LPG			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
LPG		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	19.18	21.17	22.14	23.10
IRR AFTER TAXES	%	14.77	16.26	16.98	17.69
TERMINAL WORTH (B.T.)	$	25938	25938	25938	25938
TERMINAL WORTH (A.T.)	$	82156	82156	82156	82156
PAYBACK PERIOD (B.T.)	YEARS	5.93	5.14	4.81	4.52
PAYBACK PERIOD (A.T.)	YEARS	7.95	6.93	6.50	6.14
RETURN ON SALES	%	10.49	11.66	12.22	12.78
RETURN ON FIXED ASSETS	%	11.12	12.64	13.40	14.16
DEBT COVERAGE	RATIO				
MINIMUM		1.68	1.80	1.86	1.93
YEAR		1992	1992	1992	1992
MAXIMUM		2.32	2.43	2.48	2.54
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		HYDROGEN			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
HYDROGEN		-30.00	-20.00	-10.00	10.00
IRR BEFORE TAXES	%	13.47	15.82	18.05	22.24
IRR AFTER TAXES	%	10.48	12.25	13.93	17.05
TERMINAL WORTH (B.T.)	$	25938	25938	25938	25938
TERMINAL WORTH (A.T.)	$	82156	82156	82156	82156
PAYBACK PERIOD (B.T.)	YEARS	9.62	7.76	6.47	4.78
PAYBACK PERIOD (A.T.)	YEARS	11.16	10.18	8.65	6.47
RETURN ON SALES	%	7.11	8.50	9.82	12.28
RETURN ON FIXED ASSETS	%	7.09	8.69	10.28	13.48
DEBT COVERAGE	RATIO				
MINIMUM		1.38	1.49	1.61	1.87
YEAR		1992	1992	1992	1992
MAXIMUM		1.95	2.13	2.26	2.49
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS (000) - 40 % FINANCING

SENSITIVITY ANALYSIS		GASOLINE			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
GASOLINE		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	14.07	25.68	30.74	35.48
IRR AFTER TAXES	%	10.93	19.61	23.37	26.88
TERMINAL WORTH (B.T.)	$	25938	25938	25938	25938
TERMINAL WORTH (A.T.)	$	82156	82156	82156	82156
PAYBACK PERIOD (B.T.)	YEARS	9.11	3.87	2.97	2.41
PAYBACK PERIOD (A.T.)	YEARS	10.90	5.30	4.15	3.41
RETURN ON SALES	%	7.46	14.25	17.06	19.56
RETURN ON FIXED ASSETS	%	7.48	16.28	20.68	25.07
DEBT COVERAGE	RATIO				
MINIMUM		1.42	2.10	2.47	2.83
YEAR		1993	1992	1992	1992
MAXIMUM		2.00	2.89	3.21	3.74
YEAR		1991	1991	2000	2000

APPENDIX F-3 SENSITIVITY ANALYSES (LPG QUENCH)

- in current dollars with 5% escalation per annum assuming 40% debt financing at 12% interest rate per year

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		TOTAL PLANT COST			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
MAINTEN. (INCL. LABOUR)		-20.00	-10.00	10.00	20.00
PROP. TAXES & INSURANCE		-20.00	-10.00	10.00	20.00
OVERHEAD/ADMINISTRATION		-17.30	-8.70	8.70	17.40
TOTAL PLANT COST		-20.00	-10.00	10.00	20.00
SUBSIDY:CAP. COSTS		-20.00	-10.00	10.00	20.00
SUBSIDY:HYDRO QUEBEC		-20.00	-10.00	10.00	20.00
START-UP COSTS		-20.00	-10.00	10.00	20.00
WORKING CAPITAL		-20.00	-10.00	10.00	20.00
IRR BEFORE TAXES	%	20.11	16.88	11.66	9.48
IRR AFTER TAXES	%	15.50	13.07	9.00	7.22
TERMINAL WORTH (B.T.)	$	19783	21712	25570	27499
TERMINAL WORTH (A.T.)	$	62515	69785	84326	91597
PAYBACK PERIOD (B.T.)	YEARS	5.53	7.12	10.70	11.95
PAYBACK PERIOD (A.T.)	YEARS	7.43	9.52	12.13	13.42
RETURN ON SALES	%	9.33	8.34	6.29	5.21
RETURN ON FIXED ASSETS	%	11.89	9.46	5.85	4.45
DEBT COVERAGE	RATIO				
MINIMUM		1.72	1.52	1.22	1.05
YEAR		1992	1992	1992	1992
MAXIMUM		2.44	2.27	1.90	1.75
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — NATURAL GAS

ANALYSIS No.			1	2	3	4
DESCRIPTION		L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
NATURAL GAS			-10.00	10.00	20.00	30.00
IRR BEFORE TAXES		%	17.01	10.96	7.49	3.47
IRR AFTER TAXES		%	13.17	8.44	5.57	2.29
TERMINAL WORTH (B.T.)		$	23641	23641	23641	23641
TERMINAL WORTH (A.T.)		$	77056	77056	77056	77056
PAYBACK PERIOD (B.T.)		YEARS	7.04	11.09	13.27	16.60
PAYBACK PERIOD (A.T.)		YEARS	9.41	12.51	14.83	18.31
RETURN ON SALES		%	9.32	5.29	3.17	0.97
RETURN ON FIXED ASSETS		%	9.53	5.41	3.24	0.99
DEBT COVERAGE		RATIO				
	MINIMUM		1.53	1.16	1.00	1.00
	YEAR		1992	1992	1992	1992
	MAXIMUM		2.28	1.85	1.62	1.40
	YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — ELECTRICITY

ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
ELECTRICITY		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	16.23	11.85	9.45	6.83
IRR AFTER TAXES	%	12.57	9.15	7.19	5.02
TERMINAL WORTH (B.T.)	$	23641	23641	23641	23641
TERMINAL WORTH (A.T.)	$	77056	77056	77056	77056
PAYBACK PERIOD (B.T.)	YEARS	7.51	10.61	11.98	13.76
PAYBACK PERIOD (A.T.)	YEARS	10.04	12.03	13.45	15.34
RETURN ON SALES	%	8.77	5.85	4.35	2.79
RETURN ON FIXED ASSETS	%	8.97	5.99	4.45	2.85
DEBT COVERAGE	RATIO				
MINIMUM		1.48	1.23	1.04	1.00
YEAR		1992	1992	1992	1992
MAXIMUM		2.23	1.91	1.74	1.58
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		QUENCH			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
QUENCH(LPG)		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	15.15	13.02	11.91	10.76
IRR AFTER TAXES	%	11.73	10.07	9.19	8.27
TERMINAL WORTH (B.T.)	$	23641	23641	23641	23641
TERMINAL WORTH (A.T.)	$	77056	77056	77056	77056
PAYBACK PERIOD (B.T.)	YEARS	8.25	10.03	10.58	11.20
PAYBACK PERIOD (A.T.)	YEARS	10.47	11.44	12.00	12.64
RETURN ON SALES	%	8.03	6.60	5.89	5.16
RETURN ON FIXED ASSETS	%	8.21	6.75	6.02	5.28
DEBT COVERAGE	RATIO				
MINIMUM		1.42	1.30	1.23	1.14
YEAR		1992	1992	1992	1992
MAXIMUM		2.15	1.99	1.91	1.83
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — LPG

ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
LPG		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	14.10	14.10	14.10	14.10
IRR AFTER TAXES	%	10.91	10.91	10.91	10.91
TERMINAL WORTH (B.T.)	$	23641	23641	23641	23641
TERMINAL WORTH (A.T.)	$	77056	77056	77056	77056
PAYBACK PERIOD (B.T.)	YEARS	9.09	9.09	9.09	9.09
PAYBACK PERIOD (A.T.)	YEARS	10.94	10.94	10.94	10.94
RETURN ON SALES	%	7.32	7.32	7.32	7.32
RETURN ON FIXED ASSETS	%	7.48	7.48	7.48	7.48
DEBT COVERAGE	RATIO				
MINIMUM		1.36	1.36	1.36	1.36
YEAR		1992	1992	1992	1992
MAXIMUM		2.07	2.07	2.07	2.07
YEAR		1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS — HYDROGEN

ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
HYDROGEN		-30.00	-20.00	-10.00	10.00
IRR BEFORE TAXES	%	6.98	9.54	11.90	16.19
IRR AFTER TAXES	%	5.14	7.27	9.18	12.54
TERMINAL WORTH (B.T.)	$	23641	23641	23641	23641
TERMINAL WORTH (A.T.)	$	77056	77056	77056	77056
PAYBACK PERIOD (B.T.)	YEARS	13.64	11.92	10.59	7.53
PAYBACK PERIOD (A.T.)	YEARS	15.22	13.39	12.01	10.05
RETURN ON SALES	%	3.08	4.61	6.01	8.55
RETURN ON FIXED ASSETS	%	2.94	4.50	6.01	8.94
DEBT COVERAGE	RATIO				
	MINIMUM	1.00	1.05	1.23	1.48
	YEAR	1992	1992	1992	1992
	MAXIMUM	1.59	1.75	1.91	2.23
	YEAR	1991	1991	1991	1991

LIQUID FUEL FROM NATURAL GAS (LPG QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

SENSITIVITY ANALYSIS		GASOLINE			
ANALYSIS No.		1	2	3	4
DESCRIPTION	L/F	% CHANGE	% CHANGE	% CHANGE	% CHANGE
GASOLINE		-10.00	10.00	20.00	30.00
IRR BEFORE TAXES	%	5.67	20.99	27.12	32.72
IRR AFTER TAXES	%	4.08	16.15	20.70	24.87
TERMINAL WORTH (B.T.)	$	23641	23641	23641	23641
TERMINAL WORTH (A.T.)	$	77056	77056	77056	77056
PAYBACK PERIOD (B.T.)	YEARS	14.66	5.18	3.54	2.69
PAYBACK PERIOD (A.T.)	YEARS	16.28	6.99	4.88	3.78
RETURN ON SALES	%	2.32	11.35	14.82	17.86
RETURN ON FIXED ASSETS	%	2.19	12.51	17.51	22.52
DEBT COVERAGE	RATIO				
MINIMUM		1.00	1.77	2.18	2.58
YEAR		1992	1992	1992	1992
MAXIMUM		1.52	2.49	2.84	3.38
YEAR		1991	1991	1991	2000

APPENDIX G FINANCIAL ANALYSES (HYDROGEN QUENCH)

- in current dollars with 5% escalation per annum and assuming 60% debt financing at 12% interest rate per year

- in current dollars with 40% debt financing at 12% interest rate per year assuming 3% escalation for all energy-related items and 5% for all other operating cost components

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 60 % FINANCING

P R O F I T A N D L O S S S T A T E M E N T

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	266338	310728	326264	342578	359707	377692	396577
HYDROGEN		0	0	0	96793	112920	118576	124505	130730	137267	144131
LPG		0	0	0	46087	53765	56453	59276	62239	65351	68619
TOTAL		0	0	0	409218	477422	501293	526359	552676	580310	609327
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	159332	162854	170681	179215	188176	197585	207464
ELECTRICITY		0	0	0	110271	128649	135182	141941	149038	156490	164315
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	21556	24728	25975	27274	28638	30069	31573
MAKE-UP WATER		0	0	0	551	623	654	687	721	757	795
ROYALTIES (10 YEARS)		0	0	0	3500	3890	3890	3890	3890	3890	3890
LABOUR/SUP. & OP. SUPPLY		0	0	0	3331	3498	3673	3856	4049	4251	4464
MAINTEN.(INCL. LABOUR)		0	0	0	22667	23800	24990	26240	27552	28929	30376
PROP. TAXES & INSURANCE		0	0	0	11333	11900	12495	13120	13776	14465	15188
OVERHEAD/ADMINISTRATION		0	0	0	9100	9555	10033	10534	11061	11614	12195
SUBTOTAL		0	0	0	321641	369297	387473	406632	426796	447978	470215
CAPITAL COST ALLOWANCE		0	0	0	35285	35285	35285	35285	35285	24914	24914
INTEREST EXPENSE-LOAN 1		0	0	0	52485	49494	46144	42367	38141	33485	28314
SUBTOTAL		0	0	0	87769	84778	81429	77677	73425	58399	53228
TOTAL		0	0	0	409411	453985	468901	484309	500265	506377	523533
GROSS INCOME		0	0	0	-193	23437	32392	42049	52411	73933	85794
TAXABLE INCOME		0	0	0	-193	23245	32392	42049	52411	73933	85794
INCOME TAX		0	0	0	0	8601	11985	15558	19392	27365	31744
NET INCOME		0	0	0	-193	14837	20407	26478	33019	46568	54051
RETURN ON SALES-%		0.00	0.00	0.00	-0.05	3.11	4.07	5.03	5.97	7.49	8.25
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	0.00	2.37	3.26	4.23	5.27	6.94	8.15

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 80 % FINANCING

PROFIT AND LOSS STATEMENT

	C/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		416405	437225	459087	482041	506143	531450	558022	585923	[illegible]	[illegible]
HYDROGEN		151237	158904	166849	175191	183951	193148	202806	212946	223593	234 [illegible]
LPG		72050	75652	79435	83407	87577	91956	96553	101381	106450	111 [illegible]
TOTAL		639792	671781	705370	740638	777670	816554	857381	900231	945187	992 [illegible]
ANNUAL EXPENSES											
NATURAL GAS		217837	228729	240166	252174	264783	278022	291923	306519	321845	337 [illegible]
ELECTRICITY		172402	181022	190073	199577	209556	220034	231035	242587	254716	267 [illegible]
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	[illegible]
CATALYST & CHEMICALS		33151	34809	36550	38377	40296	42311	44426	46647	48980	51 [illegible]
MAKE-UP WATER		835	877	921	967	1015	1066	1119	1175	1234	1 [illegible]
ROYALTIES (10 YEARS)		3890	3890	3890	0	0	0	0	0	0	[illegible]
LABOUR/SUP. & OP. SUPPLY		4687	4922	5168	5426	5697	5982	6281	6595	6925	7 [illegible]
MAINTEN.(INCL. LABOUR)		31894	33489	35164	36922	38768	40706	42742	44879	47123	49 [illegible]
PROP. TAXES & INSURANCE		15947	16745	17582	18461	19384	20353	21371	22439	23561	24 [illegible]
OVERHEAD/ADMINISTRATION		12804	13445	14117	14823	15564	16342	17159	18017	18918	19 [illegible]
SUBTOTAL		493449	517927	543629	566726	595062	624815	656056	688859	723302	759 [illegible]
CAPITAL COST ALLOWANCE		29904	29904	29904	29904	29904	29904	29904	29904	29904	29 [illegible]
INTEREST EXPENSE-LOAN 1		22311	15699	8294	0	0	0	0	0	0	
SUBTOTAL		52215	45603	38198	29904	29904	29904	29904	29904	29904	29 [illegible]
TOTAL		545664	563530	581827	596630	624966	654719	685960	718762	753206	789 [illegible]
GROSS INCOME		94128	108251	123543	144008	152704	161834	171421	181468	192007	203 [illegible]
TAXABLE INCOME		94128	108251	123543	144008	152704	161834	171421	181468	192007	203 [illegible]
INCOME TAX		34827	40053	45711	53283	56500	59879	63426	67151	[illegible]	[illegible]
NET INCOME		59300	68198	77832	90725	96203	101956	107996	114327	120956	127 [illegible]
RETURN ON SALES-%		9.27	10.15	11.03	12.25	12.37	12.49	12.60	12.70	12.80	12.89
RETURN ON FIXED ASSETS-%		9.46	10.88	12.42	14.48	15.35	16.27	17.24	18.25	19.31	20.42

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS (1000) - 60 % FINANCING

P R O F I T A N D L O S S S T A T E M E N T

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		678230	712194	747803
HYDROGEN		246512	258837	271779
LPG		117351	123227	129391
TOTAL		1042152	1094260	1148973
ANNUAL EXPENSES				
NATURAL GAS		354834	372575	391204
ELECTRICITY		280825	294866	309609
QUENCH(HYDROGEN)		0	0	0
CATALYST & CHEMICALS		54000	56700	59535
MAKE-UP WATER		1360	1428	1500
ROYALTIES (10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		7635	8017	8418
MAINTEN.(INCL. LABOUR)		51953	54550	57278
PROP. TAXES & INSURANCE		25976	27275	28639
OVERHEAD/ADMINISTRATION		20857	21900	22995
SUBTOTAL		797440	837312	879177
CAPITAL COST ALLOWANCE		29904	29904	29904
INTEREST EXPENSE-LOAN 1		0	0	0
SUBTOTAL		29904	29904	29904
TOTAL		827344	867216	909082
GROSS INCOME		214808	227044	239891
TAXABLE INCOME		214808	227044	239891
INCOME TAX		79879	84006	88760
NET INCOME		135329	143038	151131
RETURN ON SALES-%		12.99	13.07	13.15
RETURN ON FIXED ASSETS-%		21.60	22.82	24.12

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 obl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 80 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		56248	123543	78038	0	0	0	0	0	0	0
LONG TERM DEBT	1	77642	185261	174470	0	0	0	0	0	0	0
NET INCOME		0	0	0	-193	14837	20407	26478	33019	41461	51...
CAPITAL COST ALLOWANCE		0	0	0	35285	35285	35285	35285	35285	19904	28...
TOTAL		133890	308804	252808	35092	50121	55692	61763	68304	73366	8...
APPLICATIONS OF FUNDS											
LAND		1323	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		143614	329009	215910	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		-17232	-39481	-25909	-22673	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-22754	-23892	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	2747	0	0	0	0	0	0	0
START-UP COSTS		0	0	21587	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	21587	0	0	0	0	0	0	0
CAPITALIZED INTEREST		4395	19276	39638	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	0	0	0	24923	27914	31264	35015	39217	43923	49...
TOTAL		133890	308804	252808	-21642	27914	31264	35015	39217	43923	49...
GENERATED CASH		0	0	0	56734	22207	24428	26748	29086	29442	31...
EQUITY CASH FLOW		-56248	-123543	-78038	56734	22207	24428	26748	29086	29442	31...
ACCUMULATED CASH FLOW		-56248	-179791	-258129	-201395	-179188	-154760	-128012	-98926	-69484	-37...
DEBT COVERAGE RATIO		0.00	0.00	0.00	1.73	1.29	1.32	1.35	1.38	1.38	1.3...

LIQUID FUEL FROM NATURAL GAS (HYDROGEN BLENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 BBL/S GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS (000) - 50 % FINANCING

S T A T E M E N T O F S O U R C E S A N D A P P L I C A T I O N S O F F U N D S

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
LONG TERM DEBT	1	0	0	0	0	0	0	0	0	0	0
NET INCOME		59300	68196	77832	90725	98203	101956	107996	114237	12[illegible]6	[illegible]7[illegible]8
CAPITAL COST ALLOWANCE		29904	29904	29904	29904	29904	29904	29904	29904	29904	29904
TOTAL		89205	98102	107737	120630	128108	131860	137900	144242	151900	157882
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
CAPITALIZED INTEREST		0	0	0	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	55098	61709	69114	0	0	0	0	0	0	0
TOTAL		55098	61709	69114	0	0	0	0	0	0	0
GENERATED CASH		34107	36393	38622	120630	128108	131860	137900	144242	151900	157882
EQUITY CASH FLOW		34107	36393	38622	120630	128108	131860	137900	144242	151900	157882
ACCUMULATED CASH FLOW		-3592	32801	71423	192053	318160	450020	587920	732162	884062	1041944
DEBT COVERAGE RATIO		1.44	1.47	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 60 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
LONG TERM DEBT	1	0	0	0
NET INCOME		135329	143038	151131
CAPITAL COST ALLOWANCE		29904	29904	29904
TOTAL		165234	172942	181036
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
CAPITALIZED INTEREST		0	0	0
LOAN PRINCIPAL	1	0	0	0
TOTAL		0	0	0
GENERATED CASH		165234	172942	181036
EQUITY CASH FLOW		165234	172942	181036
ACCUMULATED CASH FLOW		1206187	1379129	1560165
DEBT COVERAGE RATIO		0.00	0.00	0.00

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	21.61	16.85
PAYBACK PERIOD-YEARS	5.79	8.10
TERMINAL WORTH	28178	82396

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
ANNUAL REVENUES											
GASOLINE		0	0	0	241921	276865	285171	293726	302538	311614	320962
HYDROGEN		0	0	0	87919	100623	103642	106751	109953	113252	116649
LPG		0	0	0	41861	47905	49343	50823	52347	53918	55535
TOTAL		0	0	0	371701	425393	438155	451299	464838	478784	493147
ANNUAL EXPENSES											
NATURAL GAS		0	0	0	126558	144839	149184	153659	158269	163017	167908
ELECTRICITY		0	0	0	100161	114629	118068	121610	125258	129016	132886
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	21556	24738	25975	27274	28638	30069	31573
MAKE-UP WATER		0	0	0	551	623	654	687	721	757	795
ROYALTIES (10 YEARS)		0	0	0	3500	3890	3890	3890	3890	3890	3890
LABOUR/SUP. & OP. SUPPLY		0	0	0	3331	3498	3673	3856	4049	4251	4464
MAINTEN.(INCL. LABOUR)		0	0	0	22667	23800	24990	26240	27552	28929	30376
PROP. TAXES & INSURANCE		0	0	0	11333	11900	12495	13120	13776	14465	15188
OVERHEAD/ADMINISTRATION		0	0	0	9100	9555	10033	10534	11061	11614	12195
SUBTOTAL		0	0	0	298758	337472	348961	360870	373213	386009	399274
CAPITAL COST ALLOWANCE		0	0	0	32739	32739	32739	32739	32739	27410	27410
INTEREST EXPENSE-LOAN 1		0	0	0	34565	32595	30389	27919	25151	22052	18581
SUBTOTAL		0	0	0	67304	65334	63128	60657	57890	49462	45991
TOTAL		0	0	0	366062	402806	412089	421527	431103	435471	445265
GROSS INCOME		0	0	0	5640	22588	26066	29772	33735	43312	47882
TAXABLE INCOME		0	0	0	5640	22588	26066	29772	33735	43312	47882
INCOME TAX		0	0	0	2087	8357	9644	11016	12482	16026	17716
NET INCOME		0	0	0	3553	14230	16421	18757	21253	27287	30166
RETURN ON SALES-%		0.00	0.00	0.00	0.96	3.35	3.75	4.16	4.57	5.70	6.12
RETURN ON FIXED ASSETS-%		0.00	0.00	0.00	0.62	2.47	2.85	3.25	3.69	4.73	5.23

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANNUAL REVENUES											
GASOLINE		330591	340509	350724	361246	372083	383246	394743	406585	418783	431346
HYDROGEN		120149	123753	127466	131290	135229	139285	143464	147768	152201	156767
LPG		57202	58918	60685	62506	64381	66312	68302	70351	72461	74635
TOTAL		507941	523180	538875	555041	571693	588843	606509	624704	643445	662748
ANNUAL EXPENSES											
NATURAL GAS		172945	178133	183477	188981	194651	200490	206505	212700	219081	225654
ELECTRICITY		136873	140979	145209	149565	154052	158673	163434	168337	173387	178588
QUENCH(HYDROGEN)		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		33151	34809	36550	38377	40296	42311	44426	46647	48980	51429
MAKE-UP WATER		835	877	921	967	1015	1066	1119	1175	1234	1295
ROYALTIES (10 YEARS)		3890	3890	3890	0	0	0	0	0	0	0
LABOUR/SUP. & OP. SUPPLY		4687	4922	5168	5426	5697	5982	6281	6595	6925	7271
MAINTEN.(INCL. LABOUR)		31894	33489	35164	36922	38768	40706	42742	44879	47123	49479
PROP. TAXES & INSURANCE		15947	16745	17582	18461	19384	20353	21371	22439	23561	24739
OVERHEAD/ADMINISTRATION		12804	13445	14117	14823	15564	16342	17159	18017	18918	19864
SUBTOTAL		413028	427288	442076	453521	469426	485924	503037	520790	539208	558319
CAPITAL COST ALLOWANCE		27410	27410	27410	27410	27410	27410	27410	27410	27410	27410
INTEREST EXPENSE-LOAN 1		14693	10339	5462	0	0	0	0	0	0	0
SUBTOTAL		42103	37749	32872	27410	27410	27410	27410	27410	27410	27410
TOTAL		455131	465037	474948	480931	496836	513334	530447	548200	566618	585729
GROSS INCOME		52811	58143	63927	74110	74856	75510	76062	76504	76827	77019
TAXABLE INCOME		52811	58143	63927	74110	74856	75510	76062	76504	76827	77019
INCOME TAX		19540	21513	23653	27421	27697	27939	28143	28307	28426	28497
NET INCOME		33271	36630	40274	46689	47159	47571	47919	48198	48401	48522
RETURN ON SALES-%		6.55	7.00	7.47	8.41	8.25	8.08	7.90	7.72	7.52	7.32
RETURN ON FIXED ASSETS-%		5.77	6.36	6.99	8.10	8.18	8.25	8.32	8.36	8.40	8.42

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

PROFIT AND LOSS STATEMENT

	L/F	2008	2009	2010
ANNUAL REVENUES				
GASOLINE		444287	457615	471344
HYDROGEN		161470	166314	171304
LPG		76874	79180	81556
TOTAL		682631	703110	724203
ANNUAL EXPENSES				
NATURAL GAS		232423	239396	246578
ELECTRICITY		183946	189464	195148
QUENCH(HYDROGEN)		0	0	0
CATALYST & CHEMICALS		54000	56700	59535
MAKE-UP WATER		1360	1428	1500
ROYALTIES (10 YEARS)		0	0	0
LABOUR/SUP. & OP. SUPPLY		7635	8017	8418
MAINTEN.(INCL. LABOUR)		51953	54550	57278
PROP. TAXES & INSURANCE		25976	27275	28639
OVERHEAD/ADMINISTRATION		20857	21900	22995
SUBTOTAL		578150	598731	620090
CAPITAL COST ALLOWANCE		27410	27410	27410
INTEREST EXPENSE-LOAN 1		0	0	0
SUBTOTAL		27410	27410	27410
TOTAL		605561	626141	647500
GROSS INCOME		77070	76969	76703
TAXABLE INCOME		77070	76969	76703
INCOME TAX		28516	28479	28380
NET INCOME		48554	48490	48323
RETURN ON SALES-%		7.11	6.90	6.67
RETURN ON FIXED ASSETS-%		8.43	8.41	8.39

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
SOURCES OF FUNDS											
EQUITY		75522	163978	113143	0	0	0	0	0	0	0
LONG TERM DEBT	1	52103	122130	113810	0	0	0	0	0	0	0
NET INCOME		0	0	0	3553	14230	16421	18757	21253	27287	30166
CAPITAL COST ALLOWANCE		0	0	0	32739	32739	32739	32739	32739	27410	27410
TOTAL		127625	286108	226953	36292	46969	49160	51495	53992	54697	57576
APPLICATIONS OF FUNDS											
LAND		1273	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		138195	310564	199924	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		-16582	-37267	-23990	-20595	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	-21070	-21702	0	0	0	0	0	0
PREPAID LICENSE FEES		1790	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	2747	0	0	0	0	0	0	0
START-UP COSTS		0	0	21587	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	21587	0	0	0	0	0	0	0
CAPITALIZED INTEREST		2949	12811	26167	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	0	0	0	16414	18384	20590	23060	25828	28927	32398
TOTAL		127625	286108	226953	-25882	18384	20590	23060	25828	28927	32398
GENERATED CASH		0	0	0	62174	28585	28570	28435	28164	25770	25178
EQUITY CASH FLOW		-75522	-163978	-113143	62174	28585	28570	28435	28164	25770	25178
ACCUMULATED CASH FLOW		-75522	-239500	-352643	-290470	-261884	-233314	-204879	-176715	-150945	-125768
DEBT COVERAGE RATIO		0.00	0.00	0.00	2.22	1.56	1.56	1.56	1.55	1.51	1.49

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
SOURCES OF FUNDS											
EQUITY		0	0	0	0	0	0	0	0	0	0
LONG TERM DEBT	1	0	0	0	0	0	0	0	0	0	0
NET INCOME		33271	36630	40274	46689	47159	47571	47919	48198	48401	48522
CAPITAL COST ALLOWANCE		27410	27410	27410	27410	27410	27410	27410	27410	27410	27410
TOTAL		60681	64040	67684	74099	74569	74981	75329	75608	75811	75932
APPLICATIONS OF FUNDS											
LAND		0	0	0	0	0	0	0	0	0	0
TOTAL PLANT COST		0	0	0	0	0	0	0	0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0	0	0	0	0	0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0	0	0	0	0	0	0	0
PREPAID LICENSE FEES		0	0	0	0	0	0	0	0	0	0
CATALYST & CHEMICALS		0	0	0	0	0	0	0	0	0	0
START-UP COSTS		0	0	0	0	0	0	0	0	0	0
WORKING CAPITAL		0	0	0	0	0	0	0	0	0	0
CAPITALIZED INTEREST		0	0	0	0	0	0	0	0	0	0
LOAN PRINCIPAL	1	36286	40640	45517	0	0	0	0	0	0	0
TOTAL		36286	40640	45517	0	0	0	0	0	0	0
GENERATED CASH		24395	23400	22167	74099	74569	74981	75329	75608	75811	75932
EQUITY CASH FLOW		24395	23400	22167	74099	74569	74981	75329	75608	75811	75932
ACCUMULATED CASH FLOW		-101373	-77973	-55806	18294	92863	167844	243173	318781	394592	470524
DEBT COVERAGE RATIO		1.48	1.46	1.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00

LIQUID FUEL FROM NATURAL GAS (HYDROGEN QUENCH)
PLANT LOCATION : QUEBEC
CAPACITY : 12500 bbl/d GASOLINE
FINANCIAL ANALYSIS - CURRENT DOLLARS ('000) - 40 % FINANCING

STATEMENT OF SOURCES AND APPLICATIONS OF FUNDS

	L/F	2008	2009	2010
SOURCES OF FUNDS				
EQUITY		0	0	0
LONG TERM DEBT	1	0	0	0
NET INCOME		48554	48490	48323
CAPITAL COST ALLOWANCE		27410	27410	27410
TOTAL		75964	75900	75733
APPLICATIONS OF FUNDS				
LAND		0	0	0
TOTAL PLANT COST		0	0	0
SUBSIDY:CAP. COST GRANT		0	0	0
SUBSIDY:HYDRO QUEBEC		0	0	0
PREPAID LICENSE FEES		0	0	0
CATALYST & CHEMICALS		0	0	0
START-UP COSTS		0	0	0
WORKING CAPITAL		0	0	0
CAPITALIZED INTEREST		0	0	0
LOAN PRINCIPAL	1	0	0	0
TOTAL		0	0	0
GENERATED CASH		75964	75900	75733
EQUITY CASH FLOW		75964	75900	75733
ACCUMULATED CASH FLOW		546488	622388	698121
DEBT COVERAGE RATIO		0.00	0.00	0.00

	BEFORE TAXES	AFTER TAXES
INTERNAL RATE OF RETURN	13.42	10.01
PAYBACK PERIOD-YEARS	8.10	10.75
TERMINAL WORTH	24337	76583